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UNRESTRICTED

# Designing Together Apart

Computer Supported  
Collaborative Design in Architecture

Submitted for the degree of  
**Doctor of Philosophy**  
The Open University  
Milton Keynes  
England

Discipline  
**Design and Innovation**

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# Abstract

The design of computer tools to assist in work has often attempted to replicate manual methods. This replication has been proven to fail in a diversity of fields such as business management, Computer-Aided Design (CAD) and Computer-Supported Collaborative Work (CSCW). To avoid such a failure being repeated in the field of Computer-Supported Collaborative Design (CSCD), this thesis explores the postulation that CSCD does not have to be supported by tools which replicate the face-to-face design context to support distal architectural design. The thesis closely examines the prevailing position that collaborative design is a social and situated act which must therefore be supported by high bandwidth tools. This formulation of architectural collaboration is rejected in favour of the formulation of a collaborative expert act. This proposal is tested experimentally, the results of which are presented. Supporting expert behaviour requires different tools than the support of situated acts. Surveying research in computer-supported collaborative work (CSCW), the thesis identifies tools that support expert work. The results of the research is transferred to two contexts: teaching and practice. The applications in these two contexts illustrate how CSCD can be applied in a variety of bandwidth and technological conditions. The conclusion is that supporting collaborative design as an expert and knowledge-based act can be beneficially implemented in the teaching and practice of architecture.



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The laboratory work described in Chapter 5 was carried out in conjunction with Alonso Vera, Robert West and Simon Lai of the Department of Psychology at the University of Hong Kong. The author of this thesis was responsible for the problem definition, 65% of the experimental design, the encoding of 50% of the transcripts and 45% of the data analysis. Chapter 5 is co-authored by the candidate and Alonso Vera, with contributions by Robert West and Simon Lai.

## Published work

Papers deriving directly from this research

- Kvan, T., Keynote speaker. (1997a) But is it collaboration. In *Challenges of the Future*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97, p. 5. Vienna: Österreichischer Kunst- und Kulturverlag
- Kvan, T. (1997b) Studio teaching without meeting: Pedagogical aspects of a Virtual Design Studio. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-T. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 163-77. Taipei: Hu's Publisher Inc.
- Kvan, T. (1998) Collaborative design communication: The Internet as a project management tool. *Design Intelligence*, 4(17), 15 September, 3-5
- Kvan, T. & Kvan, E. (1997) Is design really social. In *Creative Collaboration in Virtual Communities 1997*, ed. A. Cicognani. VC'97. Sydney: Key Centre of Design Computing, Department of Architectural and Design Science, University of Sydney
- Kvan, T., Vera, A. & West, R. (1997) Expert and situated actions in collaborative design. In *Proceedings of Second International Workshop on CSCW in Design*, ed. P. Siriruchatapong, Z. Lin & J.-P. Barthes. Second International Workshop on CSCW in Design, pp. 400-5. Beijing: International Academic Publishers, November
- Kvan, T., West, R. & Vera, A. (1997) Tools for a Virtual Design Community. In *Preprints Formal Aspects of Collaborative CAD*, ed. M. L. Maher, J. S. Gero & F. Sudweeks, pp. 109-23. Sydney: Key Centre of Design Computing, Department of Architectural and Design Science, University of Sydney
- Kvan, T., West, R. & Vera, A. (1998) Tools and Channels of Communication: Dealing with the Effects of Computer Mediation on Design Communication. [Http://www.ijvr.com/ijvr/articles/list.htm](http://www.ijvr.com/ijvr/articles/list.htm). *International Journal of Virtual Reality*, 3(3)
- Vera, A., Kvan, T., West, R. & Lai, S. (1998) Expertise and collaborative design. In *CHI'98 Conference Proceedings*. CHI'98, pp. 503-10. Los Angeles: ACM

# Acronyms

The following acronyms are used in this thesis:

A/V	Audio-Video
CAAD	Computer-Aided Architectural Design
CAD	Computer-Aided Design
CCL	Collaborative Learning Laboratory
CSCD	Computer-Supported Collaborative Design
CSCW	Computer-Supported Collaborative Work
DSL	Digital Subscriber Lines
DXF	Drawing Exchange Format
fps	Frames Per Second
ftp	File Transfer Protocol
GDDSS	Group Design Decision Support System
GDSS	Group Decision Support Systems
HLD	High Level Design
LAN	Local Area Network
LLD	Low Level Design
MOO	Mud Object Oriented
MUD	Multi-User Dungeon
VDS	Virtual Design Studios
WWW	World Wide Web

# 1 Introduction

Reflecting on how good chess players get to be good, Chase & Simon (1973) postulated that they do so through the acquisition of a substantial knowledge of complex and large configurations of chess pieces from which they can recall positions and subsequent moves when playing a game. Chase and Simon use the concept of knowledge *chunks* to explain the acquisition process, a concept which had been postulated earlier by Miller (1956, p. 93) and further developed in Simon (1979, p. 50). Subsequent research by Chase & Ericsson (1982) has shown that players can improve their performance through extended practice (of more than 200 hours). These improvements are effected not by employing larger chunks in short-term memory, but by embedding more of this knowledge into long-term memory.



When considering architectural designers working individually or together, it appears that much the same use of knowledge occurs. The more knowledge an expert has of complex and large configurations of typical problem situations (configurations in chess terms), the greater range of solutions the expert can bring to a particular problem. The chunks of knowledge with which an expert tackles a problem can be called their domain of expertise. Those with more chunks have more options and arrive at better solutions. In other words, good designs come from having plenty of big chunks available. How then does computer-mediated communication affect the ability to deploy these chunks in a collaborative setting?

There has been a wealth of research in the field of computer-supported collaborative work in the contexts of product design (Ancona & Caldwell, 1990), scientific discovery (Kraut, Galegher & Egidio, 1987-88), office management (Grenier R. & Metes, 1992), software design (Olson, Olson, Carter & Storrøsten, 1992), learning (Koschmann, et al., 1994) and policy bodies (Nunamaker, Briggs & Mittleman, 1995). This thesis looks at computer-supported collaborative work in architectural design. The title of this thesis is chosen to place it in the midst of this discussion, similar titles having been *Enterprise networking: working together apart* (Grenier & Metes, 1992), *Learning together apart* (Kaye, 1992), *Working together apart: communication and collaboration in a networked group* (Sudweeks & Allbritton, 1996).

Systems to support computer-supported collaborative work are typically divided between systems which support decision making (GDSS: Group Decision Support

Systems) and those which facilitate joint work (CSCW: Computer-Supported Collaborative Work). As I will show, most of the work in Computer-Supported Collaborative Design (CSCD) has been grounded in the heritage of situated cognition – the assumption that collaborative design is an act intrinsically grounded in the context within which it is carried out, i.e. the environment in which we find ourselves operating daily. Most implementations in the world of design have been on CSCW systems, few have looked at trying to make a group design decision support system (GDDSS?). By environment, therefore, I am referring to anything that is not knowledge in the domain of expertise, such as modes of interaction, gestures and social behaviours.

As will be discussed in Chapter 2, it is not only the context that supports design but the chunks with which we work. This view is echoed by Suwa & Tversky (1997) in their examination of the role of sketching in design. Experienced architects, they found, had more and longer chunks than students when designing (p. 403). Research in collaborative computer software design (Olson, Olson & Meader, 1997) and collaborative architectural design (as reported in Chapter 5 in this thesis) support the notion that collaborators working together on CSCW systems appear to be behaving as experts and overcoming the problems created by their context to produce consistently good outcomes coherent with their range of expertise. It is not the context that is affecting their design but their wealth of expertise and thus the range of options from which they can choose which make the difference in their ability to successfully use CSCW systems to produce good

design results. As problems arise during a design session, the solutions are found in the expertise acquired before the session, not in the particular context of the situation.

The teaching of computer applications is well established in architectural education (Kvan, 1997b). Focus is now moving to other applications of design computing in educational and professional contexts, including that of collaboration (Kvan, 1997a). Virtual Design Studios (VDS) are proliferating as the application of computers in design encompasses work in CSCW, leading to a new term: Computer Supported Collaborative Design (CSCD). Indeed, the application is so attractive that it threatens to divert the resources of design computing. Even those who are barely using computers see a potential. On a recent trip to Tong Ji University in Shanghai, a few visiting academics presented a review of recent work in the field of Computer-Aided Architectural Design (CAAD). An interesting discussion ensued with staff and leaders about the developing role of computers in supporting architectural design. Design computing as we have been working at it, for example generative systems or representational applications, did not raise much interest. The application that did evoke excitement in the teaching staff at Tong Ji was the capability to extend communication for students. They saw the possibility of engaging students in exchanges and collaborative work as being the greatest force for change and enrichment for their curriculum.



With such growing interest, it is necessary to consider the foundational theories on which we make implementation decisions. The contention in this thesis implies that for the design of computer systems to support collaborative design, the tools need to support the application of chunks, not focusing on establishing context. This position runs counter to the general trend in research and writings on VDS implementations, typical of which is the statement:

"Through these experiments we have begun to address the integration of social interaction with technical content in a geographically distributed environment. Our most important observations point out the subtlety of interactions involved in design activities, and the corresponding sophistication required of supporting communications technologies." (Shelden, Bharwani, Mitchell & Williams, 1995, p. 9)

The position expressed by Shelden, et al. leads us to focus on systems which support the transmittal of communicative acts of all types, from inflections of the voice to gestures with hands or facial muscles. Wide bandwidth is needed to convey adequately the sights and sounds that constitute the context. Most nodes on the design education World Wide Web (WWW) do not have privileged access to such bandwidth.

The contention in this thesis is that those inflections and gestures are not essential for good design outcomes. The proposition here is that it is more important to create tools which communicate design content, i.e. the chunks of the design process. There are several related fortuitous outcomes of this understanding. Chunks can be applied in narrow bandwidth conditions; for once, it is easier and cheaper to get the better solution. Expertise can be acquired in schools of design; we can begin to consider what kind of expertise might support distal collaboration



and train for it if appropriate. Even those disadvantaged schools who have difficulty getting beyond e-mail can join in on what they see as a powerful benefit of design computing. In a culinary metaphor, it is the chunks that are the nutritious components while the context which conveys the flavour.

## 1.1 Proposition of this thesis

This thesis explores the proposition that successful computer-supported collaborative design is an expert activity which can adapt to a variety of modes of communication. As such, it does not rely on tools which seek to replicate face-to-face design contexts. This proposition rests upon two related understandings — that design is not a situated activity and that designers, as experts, will successfully accomplish their work in a wide range of environments, adapting themselves and their communication to the context in which they find themselves. It follows that design is largely the consequence of the knowledge and experience of each collaborator — their expertise — not the consequence of the situation in which they design. Computer tools to support distal collaboration should therefore not seek to simulate the situations of face-to-face collaboration, but look to obtain greater benefits of the process.

As will be shown, computer software designers have already made the mistake with Computer-Aided Design (CAD) tools of trying to replicate manual methods from pre-computer conditions. In order to avoid this mistake again when building tools for CSCD, we should not be looking to tools to replicate physical

collaboration but tools to enhance remote collaboration. The conclusion is that we must look beyond our current preconceptions of needs for proximity (real or simulated) for interaction (Schmidt & Rodden, 1996) and to develop, in the terms described by Hollan and Stornetta, “tools that go *beyond being there*” (Hollan & Stornetta, 1993, emphasis added). Just as Computer-Aided Design (CAD) systems which imitate the manual process lead to trivialisation of the potentials of a medium (Flemming, Bhavnani & John, 1997), perhaps the computer-mediated studio could be an even more interesting place than the real one.

Some have suggested that better simulation of immediacy is the answer. Typical of this position is the contention by Schmidt & Rodden (1996) that the commonly used two by two matrix taxonomy of CSCW (Table 1) is incorrect because the distinction between collocated and remote participation need not be drawn since it is artificially imposed by inadequate bandwidth and poor technology.

Table 1. Common taxonomy of CSCW (after Schmidt & Rodden, 1996)

	Collocated	Remote
Synchronous		
Asynchronous		

Similarly, Coyne, McLaughlin & Newton (1996) note that a "key issue" in implementing CSCD is "replicating the full richness of face-to-face

communication (such as having visual and audio links, and working around a common desktop)" (Coyne, et al., 1996, p. 545).

This thesis will consider the alternative – that the participants of a distal collaboration will adapt themselves and their communication to the context they find themselves in. This contention parallels that found in research into the use of computers conferencing for decision making. As noted by Kurland & Barber:

Early evaluations of CCS (computer conferencing systems) were conducted on the basis of comparing group interaction in the CCS environment with communication in a face-to-face system... Such studies came in for substantial criticism by social psychologists and educationalists concerned with the design and evaluation of computer technology and by sociologists investigating the ways in which computer systems are used in various work settings... The general argument against these studies has focused on their essentially rationalist assumptions about the nature of the communication activity involved in CCS. The key implication of these assumptions is that the medium or media will have an impact on the mechanism of communication between people. The nature of the communication activity is conceived as a well-defined general system, which is independent of the participants' own construction of their social reality. For example, it is assumed that some communication channels more efficiently facilitate information exchange between end-users because they enable a higher personal/social information. Such an approach appears to deny the possibility that the form of communication activity and its meaning are negotiated by people. (Kurland & Barber, 1996, p. 58)

In other words, there was an assumption in computer conferencing systems that certain modes were needed in order to support certain types of communication and hence certain outcomes. Kurland & Barber suggest that perhaps these modes are not needed, that the users are able to work with other kinds of communication modes to arrive at desired outcomes. So, too, do we seem to be assuming in CSCD that certain kinds of communication modes to support the social interaction necessary to produce good designs. From the research described in the following chapters, especially the experimental results in Chapter 5, it appears that the role

of video and audio in design communication is similarly overplayed. We find that the participants of a design collaboration conducted over a low bandwidth computer connection are able to establish a meaningful and productive communication through action and participation. In particular, the expertise of the participants, the "chunks" of the process, appear to be more important than the context of the collaboration.

## **1.2 Structure of the thesis**

Chapter 2 of this thesis looks at collaborative architectural design, its context, structure and requirements. Chapter 3 considers reported experience in Computer Supported Collaborative Design (CSCD) and uses the findings from research into Computer-Supported Collaborative Work (CSCW) to provide a framework for evaluating the work in CSCD. Chapter 4 examines the technologies of collaborative communication. Chapter 5 offers results from experiments which looks at the issues of bandwidth and knowledge. The findings from these experiments support the conjectures offered in the first three chapters and suggests a framework to consider future development for specific tools in CSCD. Chapters 6 and 7 translate the findings from the earlier chapters into the pedagogical context (Chapter 6) and professional practice (Chapter 7). Chapter 8 summarises the findings and draws a conclusion to the thesis.



## 2 Designing together apart

As the technologies of computers and tools of telecommunication increasingly overlap, new opportunities arise for collaborative architectural design (Kvan, 1994). Of particular interest to this thesis is the application of computer tools to mediating and promoting collaborative architectural design efforts between mutually distant parties. As was the case when computers first became available to support architectural practice, technology is again ahead of practice and problems of assimilation have only begun to be explored. As so often happens when technology is introduced, we have yet to understand the implications of the technology and the opportunities offered, especially the opportunities to change the ways we work (Hammer, 1990). In rushing to implement technology, we

replicate current practice without considering the foundations on which we are making decisions (Hammer, 1990; Hollan & Stornetta, 1993).

Before deciding which tools are best suited to support distal architectural design, it is necessary to identify a framework by which to discuss design activities. This chapter forms the core of the thesis and sets out the framework in five steps. The first starts with a brief overview of the current status in architectural practice, the application of technology and the experiences of VDS's, establishing that architectural design is a collaborative activity. The second section surveys the literature of design practice and design excellence on the assumption that we should know something about the factors which affect the quality of design if CSCD is intended to support excellent, not mediocre, design. The third section extends this review into collaboration: what collaboration means and how to ensure success in collaboration. A brief historic review of design process models is presented in Section 4 of this chapter. Design process models inform us as to the ways in which computers can support design. It is noted that these models do not address issues of collaboration, a shortcoming addressed in Section 5. Here we review the theoretical analysis of collaborative design, starting first by examining the statements "Design is a social act", then "Design is a situated activity" and finally "Design is a cognitive act". The chapter concludes with a summary of the theoretical understanding of design.

The material covered in this chapter forms the background against which a review of literature in CSCW is carried out in Chapter 3. From these two foundations, we examine and propose computer tools to support collaborative design in Chapter 4.

## 2.1 An overview

Architecture is a solitary art, or so the story goes. In this version of events, the architect imagines possible inventions, wrestles with the act of creation and delivers to the world a design formed of their imagination. Fostered by popular fiction such as *The Fountainhead* (Rand, 1943) this image of the architect has been fashionable of late in Hollywood with a number of movies exploiting the theme of an isolated genius, a lone designer at an easel, attended by the muse.

At the other extreme, the reality of practising architecture for many in both design practices and in corporate or governmental offices is the experience of being a member of a team in which individual contribution is barely discernible at the conclusion of particular projects. Projects take years to complete and the compositions of teams change as transitory members contribute their specialist knowledge at appropriate moments before moving on. This version of practice is caricatured typically by a large drafting room filled with workers with eye shades and rolled up sleeves bent over drafting boards (or the modern equivalent, bathed in the glow of their CAD workstations).

While both images are faithful illustrations of some aspect of professional practice but certainly cannot be taken literally, neither tells the whole story. They both fail to portray the true collaborative nature of the profession as it has become toward the end of the twentieth century (Blau, 1984; Cuff, 1991; Muir, 1995). In even the most genius-oriented version of events, we know that the profession of architecture today is practised within a broad network of participants, all of whom help to sustain the designer, the participants ranging from client to consultant to public officials and beyond.

The network has expanded throughout the history of the profession, extending out from community to region and country and, now, to place the execution of almost any architectural commission within a global setting, in particular a global financial context. Participants in the process include colleagues, peers, consultants, a vast web of funding sources and the multitude of regulatory or supervisory agents. Architecture is, and always will be, practised in a framework which extends beyond the walls of the studio or office (Muir, 1995). Indeed, architecture has always been practised in a format which has recently come to be known as a *virtual office*, that is, a constantly changing composition of participants, joining together to realise a project or phase of a project, and reconfiguring participants for the next piece of work. Typically, this consists of colleagues and consultants in physically proximate practices, although most major projects will include consultants from out of town or out of state. Teams will employ a variety of techniques to overcome the obstacles that arise from disparate



locations, unfamiliarity with team members, poor group dynamics or other hindrances to successful collaboration.

The concepts of teaming illustrated here are not new or unusual for architectural practice. Typical construction projects are such that they have always required teams. The diversity of project types has meant that most construction has been handled by project-specific teams, disparate practices brought together for the duration of their contribution. Teaming may not be used only to bring enough manpower to the task as required. Sometimes teams are assembled in order to preclude problems from developing later in the design or construction process. As Favela, Imai & Connor (1994) have reported, Japanese construction companies employ inter-disciplinary design teams to ensure constructability and budgetary resolution early in a design process. The difference now is the location of team members can be further apart and there are new mechanisms of collaboration.

### **2.1.1 Technology in practices**

Technological tools have been much anticipated. As Wiener speculated in 1954:

Let us suppose we have an architect in Europe supervising the construction of a building in the United States... Let him draw up his plans and specification as usual. Ultrafax gives a means by which a facsimile of all the documents may be transmitted in a fraction of a second and the received copies are quite as good as working plans as the originals. The architect may be kept up to date with the progress of the work by photographic records taken every day or several times a day and these may be transmitted back to him by Ultrafax. Any remarks or advice he cares to give his representative may be transmitted by telephone, Ultrafax or teletypewriter. (Wiener, 1954, pp. 97-8)

Wiener's conjecture is not far from current practice. An architectural practice with whom I have consulted consists of a sole practitioner in a room in his house in

Pennsylvania, serving a corporate client in Connecticut by designing and supervising the construction of buildings in Honduras and the Philippines. Equipped with a laptop computer and a fax machine with the necessary number of telephone lines, all this activity takes place throughout the day as the different time zones come in to operation. While this method of practice is not the rule, it is not unusual either.

Many small or sole practices regularly serve clients on substantial projects, teaming as required for a particular task to effect a result. A report in 1994 in a professional journal ("Virtual A/E firm") identified a practice called Wayne Architects in Greenwich, Connecticut, an eight-person practice of whom four work from their homes. The team members meet about every ten days to compare notes and co-ordinate their work, but otherwise rely on modem connections. Team members change as workloads demand and members' schedules permit. Creating the team, however, does not mean bringing people physically into the office space. Instead, the team is an e-mail distribution list and a set of phone numbers. With telecommunications, the next time zone is as convenient to reach as the office next door. Practising over networks, be they dial up or not, is already a reality.

Computer tools are now a norm in almost all architectural offices around the world and the majority of design schools. Surveys carried out in the United States suggest that over 90% of architectural practices in the US now use CAD in some form (for example, Kalisperis & Groninger, 1994). A survey finds a similar

saturation in Asia (Kvan, 1995, pp. 773-4). While most implementations are mired in mundane computer-aided drafting, automating only the drawing process and only in cellular, isolated fashion without even local area networks (LAN), a few offices have begun to share data over distances and promote collaboration between remote offices. Some have moved beyond the initial step of using the Internet for exchanging data between participants and are now informing their design work from online research (Chung, 1997).

Typically, collaborative use of computers in an architectural project starts between branch offices of the same organisation or between a few engineering consultants and the architect (Laiserin, 1996; Ross, 1997). The pattern is fairly consistent: one office ships drawings off to another at the end of a discrete phase, such as the architects providing background drawings to structural engineers when the schematic design is completed. Work is done at the recipient's office using the original files as backgrounds; completed work is then plotted and collated into issued drawing sets. More recently, we have begun to see collaboration between architects in remote offices during the design effort, achieving this, for example, by passing a database of drawings at the end of each working day to another time zone where the day is just beginning and then back again as the earth moves and another face is illuminated by the sun. Thus, a building in Jakarta (Taman Anggrek II) was designed by a practice in Los Angeles (Altoon + Porter) with assistance from architects in Singapore (Heah Hong Heng & Partners) knowledgeable of particular Indonesian conditions. This pattern of document



exchange is the norm. The survey of reports on practice in Chapter 3 (page 136 below) reveals that a characteristic of a majority of collaborative use of computers in design today is its asynchronous nature. Few of the professional implementations to date apply computer tools to interactive synchronous design.

### **2.1.2 Virtual design studios**

While professional practices have been expanding their use of computers, so too have schools of architecture. Some institutions have pioneered by conducting research into the fundamentals of design computing, others by training their students to use commercially produced computer tools. In recent years, however, schools of architecture have realised that networks offer an opportunity to bring students from disparate schools together to work as teams across cultural, political and geographic boundaries. The value of a VDS in the educational context is examined in Chapter 6 of this thesis.

My interest in this subject started with one such experience. Six schools of architecture in five different time zones and three continents joined together and brought together a group of design students to tackle a common problem. Schools of architecture in seven universities (Barcelona, British Columbia, Cornell, Harvard, Hong Kong, MIT, Washington in St. Louis) joined together for two weeks to devise new housing models for an area of Shanghai scheduled for redevelopment. The exercise, known as the Virtual Design Studio, is described in detail in Cheng, et al. (1994), thus introduced time zones, culture and geography as variables with which the students had to deal.



In the 1994 exercise, the students used as tools for communication and collaboration a variety of systems, reflecting the concerns and direction of the individual schools. Each school handled the design task as they wished — some formed teams while others allowed the students to tackle the problems individually. A server was set up in Vancouver to which files for sharing were posted — in effect a digital “pin-up board” as it has come to be known (as defined in Wojtowicz, Papazian, Fargas, Davidson & Cheng, 1993, p. 107). Scanned images, structured CAD models and ASCII files were posted to be downloaded using ftp (File Transfer Protocol, a utility by which a user can copy a file from one server to another, typically bundled into web browsers) when convenient. Access to the pin-up was unrestricted for participants — anything could be uploaded or downloaded as needed.

This interaction was supplemented by e-mail messages that grew to have distribution lists that filled a screen. Further interaction was achieved at different times during the project by using various shareware tools which were readily available at no cost to users: Collage (obtained from [ftp.ncsa.uiuc.edu](ftp://ncsa.uiuc.edu)) for whiteboard functions; vat (Visual Audio Tool, obtained from [ftp.ee.lbl.gov](ftp://ee.lbl.gov)) and CU-SeeMe (obtained from <cu-seeme.cornell.edu>) for video and audio communication; ftp; and talk, a UNIX chat program for synchronous text communication.

Students were asked initially to exchange ideas for design solutions using any media they chose, to comment on each other's solutions and to encourage a

discussion of approaches. The second half of the exercise was then used to develop more detailed models and renderings to describe particular design solutions promoted by each team (or individual). Original intentions to promote and encourage interaction over the designs failed, for reasons explored below. At the end of the two weeks, we held a video conference call bringing together all the participants for two hours of intercontinental presentation and review.

Today, virtual studios proliferate. In the period between 1993 and 1998, the topic has become a standard component of conferences on architectural computing. A survey of papers in the three major annual conferences on educational architectural computing in this period — CAADRIA (in Asia), eCAADe (in Europe), and ACADIA (in North America) — shows a growing in the number of presentations on the subject with three reported in 1993, one in 1995, four in 1996 and eight in 1997 (these papers are reviewed in Chapter 3). Indeed, the anticipated impact of virtual design studios was such that early on a conference was entitled "The Virtual Studio" (the 1994 eCAADe conference). Subsequent conferences held around the world have picked up the theme and it is now common to find several conferences each year with addressing this theme.

## **2.2 Architectural design**

Central to any discussion about computer tools to support architectural design lies the conundrum of defining design itself. There is extensive literature around the question "what is architectural design" (for example, Lawson, 1980, Lawson,

1994). There is additional literature that tries to address the more general question “What is design?” (for example, Dorst, 1996). Others have considered the difference between design in physical worlds and design in virtual worlds (see Bridges & Charitos, 1997).

In all models of the design process, though, we find in common the activities of cogitation, expression/modelling and communication/testing. Without engaging in discussion about computer-mediated cogitation or to speculate on what the results of computer-supported collaborative design might be, we can observe electronic interaction affecting the *process* of design. In particular, we can consider ways in which computer-supported collaborative design collaborations might be conducted. Before this is possible, however, it is useful to consider the architectural design process, not to catalogue actions for replication but to gain an understanding of goals and processes along the way.

In practice, an architect draws upon a wide variety of media to express his or her ideas. Within the course of a project, different representations are used at different times to explore different issues (Lawson, 1994, p. 90). An architect can expect to produce drawings using transparent and opaque paper, even the back of an envelope, using pencils, ink and paint. Drawings may be soft edged or hard lined, fuzzy or precise. Models might be created, employing card, clay, plastic, metal and almost any other material. For example, trees on a model might be made from branches of bushes, sponge, paper or plastic. A project might be explained using words, numbers, and charts (Lawson & Loke, 1997). Contracts and legal

documents accumulate and records are kept of all manner of exchanges of information.

As these data gather, a designer begins to identify constraints, opportunities, references and allusions that might be important to setting a direction for a solution. Diagrams are drawn for such things as major circulation flows, dominant axes, or structural problems. These will be supplemented by more detailed partial solutions, ranging from how an entrance might work to building components. References may be made to earlier solutions and searches will be made to find these precedents. As this work proceeds, an architect accumulates sketches of space in two or three dimensions, using conventional representations like perspectives, plans, elevations and sections. Some particularly complex spaces must be created in model form so they can be picked up, turned around, to be torn and re-glued as ideas evolve. Additional thoughts are represented by studies in texture or light or by technical data and calculations. Meetings are held with clients, consultants, colleagues to explore ideas, review progress and solicit input.

As design ideas are expressed, a significant difference between manual drawings and computer-based images becomes apparent. There is a perceived level of specificity in all computer output, be it word-processing or drawings. Laser-printed text looks final, no matter how it is labelled. Aligned pixels seem more definite than smudged graphite. Designers will use this to their advantage, choosing a representational medium to desired effect (Robbins, 1994). This has some implications on the quality of communication achieved — a vague image



invites interpretation while crisp lines imply resolution (Lawson, 1994, p. 90). These differences can be used to advantage too — the degree of specificity must change as the design progresses and decisions are made.

At earlier design stages in particular, ambiguity plays a major role, both in communicating the design to others and to oneself (Goel, 1995; Schön & Wiggins, 1992). Much of the perceived freedom in traditional materials stems from ambiguity or the ability of each perceiver to interpret results in their own way. It is true that some early design information is precise, that there is little opportunity for reinterpretation on the part of the receiver. Much is vague, however, and reinterpretation is essential to a design dialogue (Goldschmidt, 1991; Goldschmidt, 1994; Lawson & Loke, 1997). Lines are tentatively drawn, reserving the right to be changed later. Emergent forms are discovered and interpreted (Suwa & Tversky, 1997; Verstijnen, et al., 1998).

Research has only recently begun to look in detail at the architectural design process so our understanding still relies heavily on empirical and anecdotal evidence. One area in which we have little detailed understanding is the role of misunderstandings and interpretation. Anecdotal evidence suggests that fortuitous misinterpretation also plays a part in creativity, reminding us that clarity is not desired at all times. Designers can misinterpret and reinterpret their own sketches or annotations as well as communications from their colleagues or even the client. Others have called this emergence (Soufi & Edmonds, 1996) or discovery (Purcell & Gero, 1998). The role of misinterpreted communications in history, science or

politics is perhaps better documented than that in design but undoubtedly occurs as frequently.

In practice we see that architects believe the means of representation used affects the degree of ambiguity allowed (Robbins, 1994; Lawson, 1994). In design communications, thick, broken or incomplete lines contribute to the ambiguity. This is why many designers prefer to work at first with soft pencils, rapid marker strokes and rougher paper, then moving to ink on smooth mylar later (Robbins, 1994). Computer drawings imply finality (Lawson, 1994, p. 90). To reintroduce some of the ambiguity into overly precise CAD drawings, some users employ software to render the precise digital drawing in one of three line styles — back of the envelop swiggly, freehand drawn slightly more precise and hard line finality.

As we consider applying computer tools to the design process, we need to keep these multiple representations in mind. In digital terms, this suggests, for example, that bit-mapped images appear to hold greater promise at the early stages of a design cycle while the precision of a structured computer graphics model reflect the less flexible phases of a later design stage. All this is compounded by strictures placed by particular software systems which require the user to act in a particular pattern or sequence. The freedom and spontaneity of traditional media is perceived to be lost in the digital realm both from the means of representation as well as methods of interaction. These losses are not inherent in the media but are introduced in the inappropriate design and implementation of software.

When thinking about using computers for collaboration it is necessary to remind ourselves that the perceived unsuitability of computers for architectural design arises not from the computers themselves but from a mismatch of the tool to the outcome or process to achieve the outcome. Tools should be created to support the essential aspects of design. By the same token, we must not fall into the trap of replicating non-computer methods without considering the ways in which work can be restructured to advantage (Zuboff, 1988; Hammer, 1990).

### **2.2.1 Designing together**

The act of designing is an act that involves others. While we may speak of "Utzon's Sydney Opera House", associating the building with a particular designer, we know this does not describe the individuals who were integrally involved in realising the design. Cuff (1991, p. 76) reports that some architects consider collaboration to be less rewarding, that "the more participatory the process, the more time-consuming and the less profitable." For most architects, however, the process of designing benefits from the participation of other members of their profession and members of other professions.

As the professions involved in construction evolve, the role of the architect has changed (Gutman, 1988). These changes have been seen to dilute the authority of the architect and hence his ability to claim control of the design. Thus architects may fear losing control of the design through the necessary collaboration. For most architects who are not fearful of the participation, the explanation by Edward

Cullinan is illustrative: "I mean we are designing together but really I have to stress that the ideas are really ours." (Robbins, 1994, p. 64).

Some people hold this as an ideological position – for example, those who hold the belief that the only good design is participatory design. Work such as Alexander (1968) has attempted to formalise this position into a design methodology. On the other ideological side, Howard Roark, hero of *The Fountainhead* (Rand, 1943), defines an image which still persists. The brazen hero, working in defiance of society or preconceived notions of design delivers to a client a design that must be accepted if the client is to be saved from being branded an ignominious ignoramus. No evidence can be found in professional practice to support this latter position. As Charles Moore noted, "Rejecting any sorts of attitudes of secrecy or doing work in isolation is important. And speaking out against the attitudes in *The Fountainhead* every chance one gets is important." (Anthony, 1991, p. 205).

What can be seen then is that collaboration is inherent in good design, much to the disappointment of those who subscribe to the image of the isolated genius. Building design projects draw upon variety of specialists. Chappell and Willis, authors of the standard British teaching text for architectural professional practice (Chappell & Willis, 1992) start their book, Chapter 1, Section 1.1, with a review of the participants in the construction industry, listing eight "people" or entities involved (employer, architect, quantity surveyor, structural engineer, services engineer, landscape consultant, clerk of works, contractor) and two more general



terms which suggest many other participants (specialist consultants, sub-contractors). The American Institute of Architects Handbook of Professional Practice lists 33 participants in addition to the architect and employer, six of whom are primary consultants, the remainder "additional consultants" (American Institute of Architects, 1975). Cuff calls this "a highly optimistic, if not unrealistic, view" (Cuff, 1991, p. 77), noting from her observations that up to 67 participants can be identified. With the specialisation of knowledge, the number of participants in a project is growing (Tombesi, 1997). Whatever the number, it is more than one.

Collaboration in a design team is somewhat different from that of general collaboration (building a sandcastle, for example). Professional architectural work is bounded by a very large set of constraints: professional ethics, licensing, legal, risk, safety, ergonomic, etc. These constraints limit the assumption of roles and realms of discussion. Collaboration within a particular professional team (that is, where all members come from one practice) is different — the professional bounds are loosened and different dynamics occur. Thus, when we are translating findings in collaborative acts in other settings into the world of architectural practice, we need to consider the professional setting and its intrinsic conditions as well.

While considering collaboration in practice, we can remind ourselves that what is done in practice is influenced by teaching in professional schools of architecture. While collaboration may be at the heart of professional work it is often denied by

the teaching. Courses often celebrate the individual designer and design studios isolate students into contests one against the other. An examination of computer-mediated collaborative design is therefore doubly interesting as a pedagogical issue (Kvan, 1997c).

### **2.2.2 Supporting design excellence**

Thomas Kuhn (1970) has proposed that scientific discovery does not happen in a linear and incremental fashion but through fundamental changes of world views or paradigm shifts, as he called them. Observation suggests that good design, likewise, is not a serial exchange of ideas in which elements are added sequentially by participants nor does not arise from quiescent acceptance. Analysis of successful design outcomes, such as that by Cuff (1991) or the American Institute of Architects (Shibley, 1989) suggests that successful collaboration thrives on “warm, almost familiar relations among the actors, as well as conflict and, at times, tension.” (Cuff, 1991, p. 234). In addition to the relations between participants, however, it depends upon the roles of the participants.

The co-location of design team members is currently promoted by many as the means to improve design. For example, several large corporations in the United States, including Chrysler Corporation and Sun Engineering, have built research and engineering buildings with the assumption that co-location will bring beneficial results in product development and product quality (Ettorre, 1995).

There remain instances, however, when members of a design team cannot be physically present in one place over the course of a close collaboration. The reality of architectural design projects today is that they involve members at distant locations more often than not. Sometimes clients require the team members to co-locate in order to foster better collaborative processes and better outcomes. Can computer-supported collaborative design systems achieve the same beneficial effects as co-location?

While we might be able to identify examples of teams designing collaboratively, how are *good* designs brought about? How do the participants interact constructively? While almost as vague as subject as “what is design”, we are fortunate to have some useful documentation of processes which have led to good design.

The American Institute of Architects sponsored in 1989 a series of roundtable discussions, workshops, panel discussions and conferences on the subject of ‘excellence in design’. The workshops were part of the *AIA Design Practice for the 90’s* programme and the results were documented in Vonier (1989). Although there are rightly multiple definitions of excellence (Shibley, 1989 discusses the problems inherent in the search for a definition) and likewise many hypotheses on how excellence is achieved, a broad consensus evolved from this effort about some of the conditions for producing design excellence.

The conclusion of the workshops is that excellence is achieved when the designer knows the participants and the problem well and when this leads to a shared definition of the problem (Coxe, 1989). The AIA organised two roundtables — one for ‘signature firms’ (those in which an individual talent leaves a unique mark on a body of excellent work) and another for ‘star’ firms (those practices which have left a consistent body of good work, stemming from stable management and design methodologies). These two approaches cross-checked findings and led to strong consensus on preferred approaches to achieve excellence. The participants of the roundtables noted that they work both individually and collectively with clients and consultants to understand the issues of a design problem and to explore solutions. Indeed, a group of ‘signature’ firms identified that excellent design projects were characterised by substantial time being spent on the processes of exploration and gaining trust of those involved in the project, this period of the project being known as ‘pre-design’ work (Coxe, 1989).

Another source sheds useful insights on the role of individuals in the design process. After a close review of three case studies which led to good design outcomes, Dana Cuff has characterised the process as:

“... a team-like sensibility bonded the central players who struggled together to create the excellent outcome, but these individuals did not necessarily participate equally or collaboratively. Instead, key individuals played key roles; their talent and authority was reported to be essential to the building’s success” (Cuff, 1991, p. 241).

As Cuff identifies, the participatory process needs to allow individuals the opportunity to find for themselves appropriate roles by which to deliver their



particular contribution. This contribution does not have to come from close team collaboration. As in her earlier work (Cuff, 1989), Cuff notes that key individual may contribute through what she calls "teamwork with independence" in which the key participants participate unequally. She notes that the participation may be co-operative rather than collaborative (Cuff, 1989, p. 84), an aspect of team work explored in Section 2.3 below.

In the extract above, Cuff notes too that the contribution from these individuals is in their talent and authority. Talent must be interpreted to be more than the innate characteristics of a creative person since she refers in her examples not only to the designer but also the client and key consultants. Talent then is the knowledge, expertise and experience of these participants as well as their well developed ability to interpret and bring these to bear on the project.

Cuff suggests that the participants must have this "team-like sensibility" for the teamwork to lead to successful outcomes. Such a sensibility arises from a commitment to participate (Cuff, 1989, p. 84). While the problems exist in all settings, the difficulties of participation are acutely obvious in computer-supported collaborative design. The participants in a group must submit to a consignment, in the terms of Vaitkus, "simply submitting and giving oneself over" to the process and the fellow participants. As Vaitkus has noted, it is difficult enough to submit within a known group, but even more difficult when the colleague is unknown.

“The milieu cannot readily accept a new and, thus, anonymous member without forsaking its distinctive, private, familiar character which gains its significance precisely in opposition to such anonymous others.” (Vaitkus, 1991)

Vaitkus notes that we employ "social offerings" (Vaitkus, 1991, p. 166) to fulfil in part our fiduciary obligations — these are the gestures of attentiveness to others within the group such as responding to initiatives of others or offering tokens of comfort. These gestures are such actions as turn taking, deferral, inclusion and attentiveness. In face-to-face communication we have a ready and well-practised range of such offerings. We are less well equipped to accomplish this fiduciary role within the context of computer-mediated communication because, in part, we have less experience and therefore a more impoverished catalogue of actions from which to choose. Experience can help us overcome this problem and enrich the catalogue of gestures.

At what level do you try to establish success in architecture? Architectural practices can try to implement changes to move toward more successful habits but this may not be the most appropriate. Coxe (1989) and Cuff (1989) identify that successful architectural outcomes appear to arise from a project focus. Practices which produce consistently good buildings operate without an overarching concern about the practice and pay greater attention to the projects individually. The implication is that a good practice comes from a collection of good projects fostered within an environment conducive to good projects.

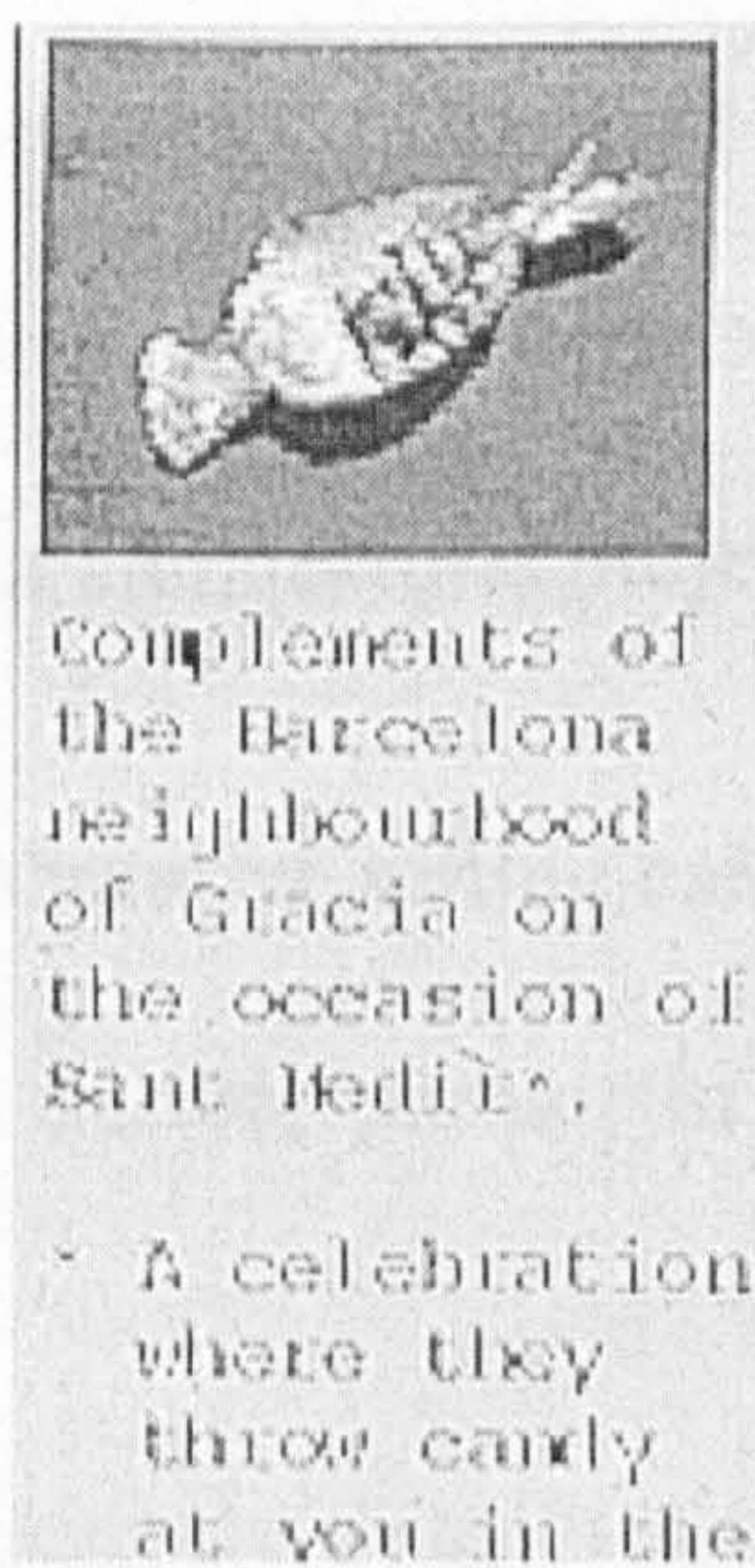
The problems are not unique to the world of computer-mediated communication. In the context of a professional activity, we regularly find ourselves in new

situations in which we have to enter a group or accept into our group a new participant, an anonymous person (even if they appear in physical form) and integrate them into the transactions of the group. In a business setting there are many rituals of inclusion in which we engage. In the world of computers, such rituals are evolving among those who participate in bulletin boards, MUDs (Multi-User Dungeon — the name comes from the first application in text-based multiparticipant games based on Tolkenian themes, hence dungeons) and MOOs (MUD Object Oriented — a less sinister application of text systems to create virtual place) (Turkle, 1995). Our experience with CSCD is so limited that, as yet, we have not established such social formalisms.

In the same way that cultural differences can hamper communication when you travel, choosing appropriate communicative gestures during CSCD is important and even difficult. This is particularly important early in projects as teams work to establish the roles to which we referred above. If you accept Cuff's findings, then expressions of personal characteristics become even more important as key individuals assert themselves. Participants can express these characteristics in many ways, not just visually or aurally. An experience during the 1994 VDS (documented in Wojtowicz, Cheng & Kvan, 1995 and Cheng, et al., 1994) illustrated the power of personalisation in communication. The University of Barcelona students undertook a very formal, algorithmic approach to design, generating a matrix of permutations which looked forbidding. Students used to less formal approaches to design found it difficult to react to this work and had a



forbidding impression of the Barcelona participants. This changed dramatically when Barcelona's students established an identity and character for open interaction, for fun, by posting images of candy (Figure 1) distributed during a carnival which took place during the time of the VDS, supplemented with quotes taken from various texts. This helped recipients of their more intellectually challenging (and forbidding) messages react openly when these came later. These ephemera created an attitude which video cameras or audio connections could not have done, especially in a multi-lingual (in our case, Spanish and Cantonese), multi-cultural experiment as we held.



**Figure 1:** Image of candy from Barcelona

There is one last point to consider in the issue of architectural design excellence. In order to achieve excellence, the participants must be open to evaluative comments from others. Among the personal characteristics which affect design in particular is a person's self-image. Design is an ego-laden activity. A participant



invests in the created object or image a measure of their personal being. A collaborative process requires the design contributor to be willing to step back and permit the other participants to amend the design. For a constructive design collaboration to occur, the participants must come to a tacit understanding that their contributions will be valued. As Vaitkus (1991) notes, the participants in a group carry a fiduciary responsibility to others within the group which he describes as:

"an act of credulity...a certain 'predisposition' or 'readiness' to be open to believing in the other..." (Vaitkus, 1991, p. 163)

Thus the participants in a collaborative activity must be prepared for the process in part by opening themselves to others. There are different ways of preparing the participants. One method is to engage in "team building", a common activity in corporations and increasingly in architectural project teams (Piven, 1996).

It has been noted that the collaborative setting can be beneficial when faced with the problem of ego. Richard Burton, partner in Ahrends Burton Koralek, has observed:

The group has a distinct advantage over the individual because ideas can become personal property or one's own intellectual territory. The strength of that territory is considerable, and the difficulty of working alone is often in the breaking of the bonds caused by it. With a group the bonds are broken more easily, because the critical faculty is depersonalised. (quoted in Lawson, 1994, p. 10)

Depersonalisation of the product is often presented as a negative attribute of the conditions imposed by remote collaboration but here Burton presents us with a positive outcome of this situation. Research findings into e-mail communications have found that electronic conversations attenuate contextual cues, resulting in a

reduction in status differences. In the case of written interactions, Sproull and Kiesler have noted

“The results confirmed that the proportion of talk and influence of higher-status people decreased when group members communicated by electronic mail” (Sproull & Kiesler, 1991, p. 120)

Thus the conditions of remote collaboration can potentially help to reduce problems of ego and protectiveness in design criticism.

### **2.2.3 Summary**

This section has reviewed the process of design as observed in practice. The distinction between designing alone and designing in a team is drawn to identify the issues which may arise in a team setting. In particular, the section considers how design excellence is achieved and how this might be affected by team conditions. Finally, the section considers the necessary conditions for a team to work successfully.

We have identified that design is indeed collaborative, even in the smallest of projects. Design is not a clear process in which each action is clearly understood. There are strengths which derive from the collaboration which are important, allowing collaborative projects to be better than ones relying on singular individuals. Design excellence is arrived at by focusing on the project and ensuring that the participants come together to form a team, each with their own knowledge to contribute and not always in harmony. The team is built upon participation and acceptance.

The follow section extends this discussion by looking at the nature of collaboration in greater detail and draws some conclusions about achieving collaborative success.

## 2.3 What is collaboration?

It has become accepted practice to use the term “collaborative systems” to describe the computer systems which support distal communication between designers. Sometimes the term “co-operation” appears to be used interchangeably with “collaboration”, as in the journal name *Computer-Supported Cooperative Work* or the paper *Exploring communication in collaborative design: co-operative architectural modelling* (Peng, 1994). In this thesis the term *computer-supported collaborative design* is used.

In using the terms co-operative or collaborative, we also assume some of the misinterpretations of the words, as already noted by Easterbrook:

The word *cooperative* in computer supported cooperative work (CSCW) is frequently taken for granted. It is assumed that people who use a CSCW system want to cooperate and can actually do so without difficulty. This assumption ignores the possibility of conflict, and hence the management and resolution of conflict are not supported. In some cases, a CSCW environment might not even allow conflicts to be articulated, causing misunderstanding and frustration. (Easterbrook, 1993, p. v, emphasis original)

As Easterbrook points out, the process of working together is not a smooth and seamless event, unlike the inference of the term “co-operative design”. The substitution of the term “collaborative” for “co-operative” suggests that an analysis of the terminology may illuminate different ways of collaborating.

### 2.3.1 Collaboration and Co-operation

It was noted earlier that Cuff has observed that participants in collaborative design "did not necessarily participate equally or collaboratively." (1991, p. 241). Similar comments are made by others, as can we all from our own experience. Simply working together or talking about the same subjects does not make the act collaborative (Sudweeks & Allbritton, 1996). What specifically makes these acts of collaboration or not? Is there any importance in the name applied to this field of study (CSCW) which is sometimes rendered 'computer-supported collaborative work' and at others 'computer-supported co-operative work'?

Part of the problem is that the activities undertaken vary in intent and participation. Is a crew of a ship guiding it into port collaborating with the pilot who has come on board as it enters the harbour? The pilot points out the hazards, the captain issues commands to the crew. Is their working together not one of co-operation? What is the distinction? Likewise when two or more designers are working together on a building, when are they collaborating and when are they co-operating? Design projects have many stages, some lasting long periods and others quickly over, in which the nature of the participation is different.

The roots of the words are, of course, frustratingly similar, but they do carry distinctions worth pursuing. Indeed, the Oxford English Dictionary defines collaborate as "to co-operate, especially in literary, artistic or scientific work", deriving from the Latin words *col labore*, to work along side one another. Collaboration can be thought of as joint problem solving. It means working with



others with shared goals for which the team attempts to find solutions that are satisfying to all concerned.

Co-operation, as the Oxford English Dictionary tells us, is “to work together, act in conjunction... to co-operate for ... mutual benefit” from the Latin *co operari*, to work with or along side. The dictionary also tells us that co-operation is an older concept (the first instance dates from 1616) while collaboration appears in the English language only in 1860, perhaps suggesting that co-operation is a simpler concept than collaboration.

From their survey of literature in collaboration, Mattessich and Monsey have defined the words more thoroughly and have drawn a third distinction, that of co-ordination:

- *Cooperation* is characterized by informal relationships that exist without a commonly defined mission, structure or effort. Information is shared as needed and authority is retained by each organization so there is virtually no risk. Resources are separate as are rewards.
- *Coordination* is characterized by more formal relationships and understanding of compatible missions. Some planning and division of roles are required, and communication channels are established. Authority still rests with the individual organization, but there is some increased risk to all participants. Resources are available to participants and rewards are mutually acknowledged.
- *Collaboration* connotes a more durable and pervasive relationship. Collaborations being... (a) full commitment to a common mission... Authority is determined by the collaborative structure. Risk is much greater... (Mattessich & Monsey, 1992, p. 39)

As Mattessich & Monsey make clear, collaboration requires a greater commitment to a common goal than co-operation with an attendant increase in risk. For this to occur, the level of trust must be higher.

This consists of accepting all parties agreeing on the problem definition (or sufficiently so that a common effort can be made), sharing concerns as valid and digging into issues to find innovative possibilities. It means being open and exploratory. It implies a deep level of trust and acceptance. As Vaitkus notes:

...the fiduciary attitude can be generally understood as an attitude of credulity in the sense of being a certain predisposition or readiness to be open to believing in the other. I can never be completely assured that I have in fact reached an intersubjective understanding with the other and, consequently, I must for this reason always and primarily rely upon a fundamental trust in the other, (Vaitkus, 1991, p. 164)

In their observations about ten years of experience at Xerox PARC in using the Media Space, Harrison, Bly, Anderson & Minneman have also noted that trust is integral to the success of the project (Harrison, et al., 1997, p. 297).

Design collaboration therefore requires a higher sense of working together in order to achieve a creative result than co-operative design. It is a far more demanding activity, more difficult to establish and sustain, than simply completing a project as a team. It should be noted that collaboration does not imply capitulation by individual members nor does it imply decisions by consensus (a common mistaken assumption, see for example Caneparo, 1995).

I suspect that we collaborate far less often than we pretend to. We focus on collaboration and I have tried to distinguish that act from co-operation. Most design projects bring teams into a relationship that fits Mattessich & Monsey's definition of co-operation or co-ordination more closely than it fits their definition of collaboration.

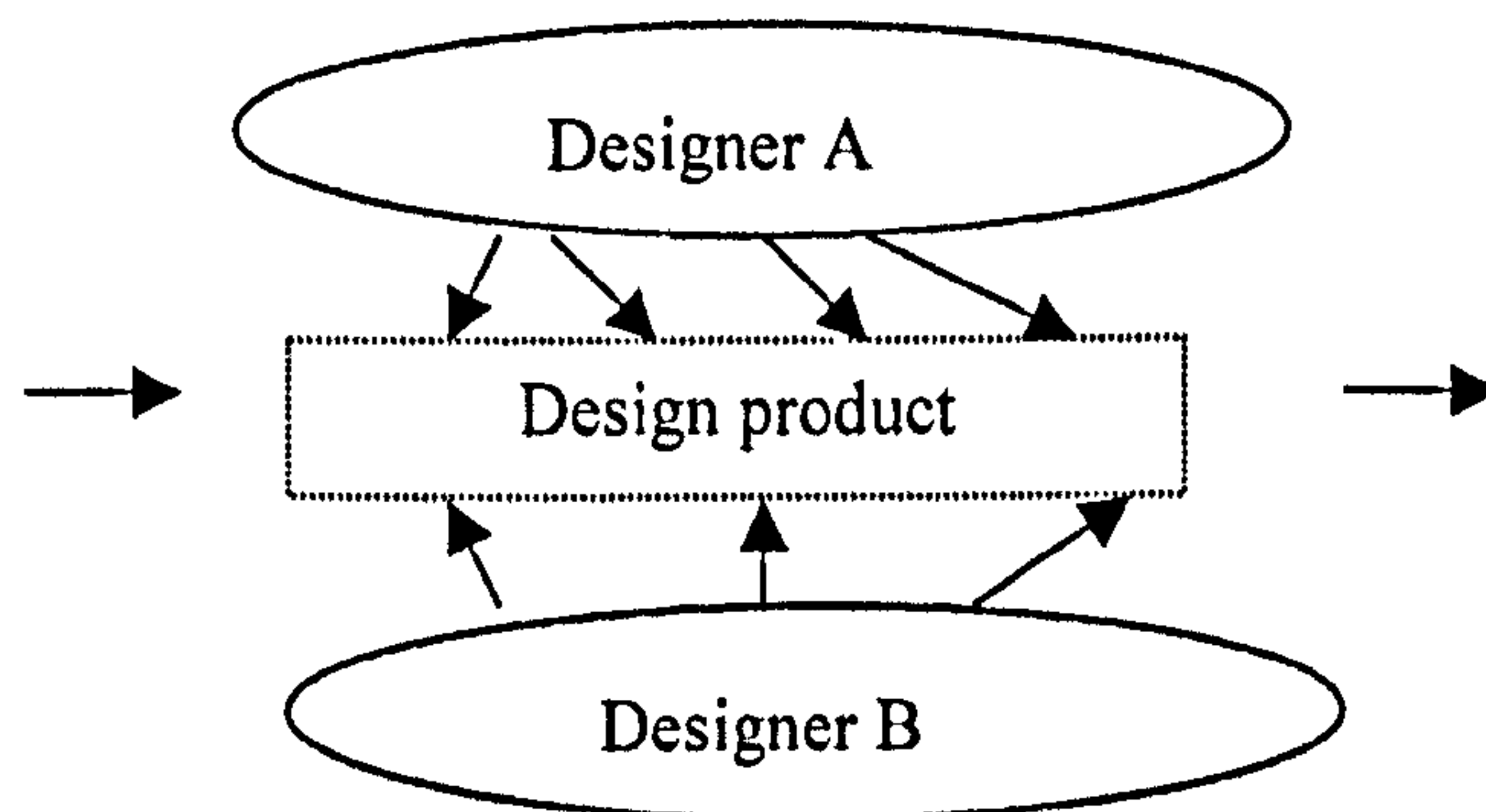
But if we look further at collaboration, we see one more issue – compromise. Compromising suggests an expedient settlement that only partially satisfies those involved. It doesn't dig into underlying problems but rather goes for a superficial arrangement. In the model proposed in this thesis (the cognitive model of design, Section 2.5.3 below), the compromising occurs in the negotiation and evaluation steps, steps in which the problem at hand is redefined and the problem adjusted as work continues. This indeed is borne out by Dorst (1996, p. 25) with his observation that designers practice “satisficing” very often. In Cross & Cross (1995, pp. 166-168) for example, collaborative designers reach design decisions which are not the best solution but which are adequate. This is not a pejorative to be dismissed, for the basis for the satisfied solution goes beyond superficiality and is often a truly innovative solution.

### **2.3.2 Close coupled or loose coupled?**

Until recently, architectural process models did not try to account for collaborative activities. Collaboration is assumed to be a context of the work which does not need to be articulated in order to understand design itself. As we have come to look more closely at team environments, this omission has had to be addressed.

We might think of collaborative design as a continuous close coupled process in which the participants work closely to realise a design (see Figure 1). Here, the participants work intensely with one another, observing and understanding each other's moves, the reasoning behind them and the intentions. Inflections and

intonations in verbal communication are thought to be critical in conveying meaning in the intense exchange. At any stage of the design, the observer cannot identify a discrete contribution to the design product from one participant or the other.



**Figure 2:** Close coupled design process

If you ask a design team what they were doing, the participants typically will not think of a time when they are not designing. They will describe a complex series of decisions, threads that were picked up and dropped, tasks and events that occurred. Post-rationalised, these threads may seem to exhibit a structure and the process a plan. Typically, designers will describe intense and extended periods of time when they worked intensively together to solve the design problem followed by periods of individual activity and even apparent inactivity. Observations by participants in a collaboration suggest otherwise.

Earlier work on the organization of software design activities showed that notions of a predefined sequence were misguided and that, not only is design characterized as a loosely structured process, but that designers are able to handle different levels of the abstraction at the same time. (Candy & Edmonds, 1977, p. 187)



The participants have been engaged to work together because each has a particular expertise that can be contributed to the solution process. In this situation, we see two or more experts operating in their own domains on a shared problem and at different levels of abstraction concurrently. Is this true also of design?

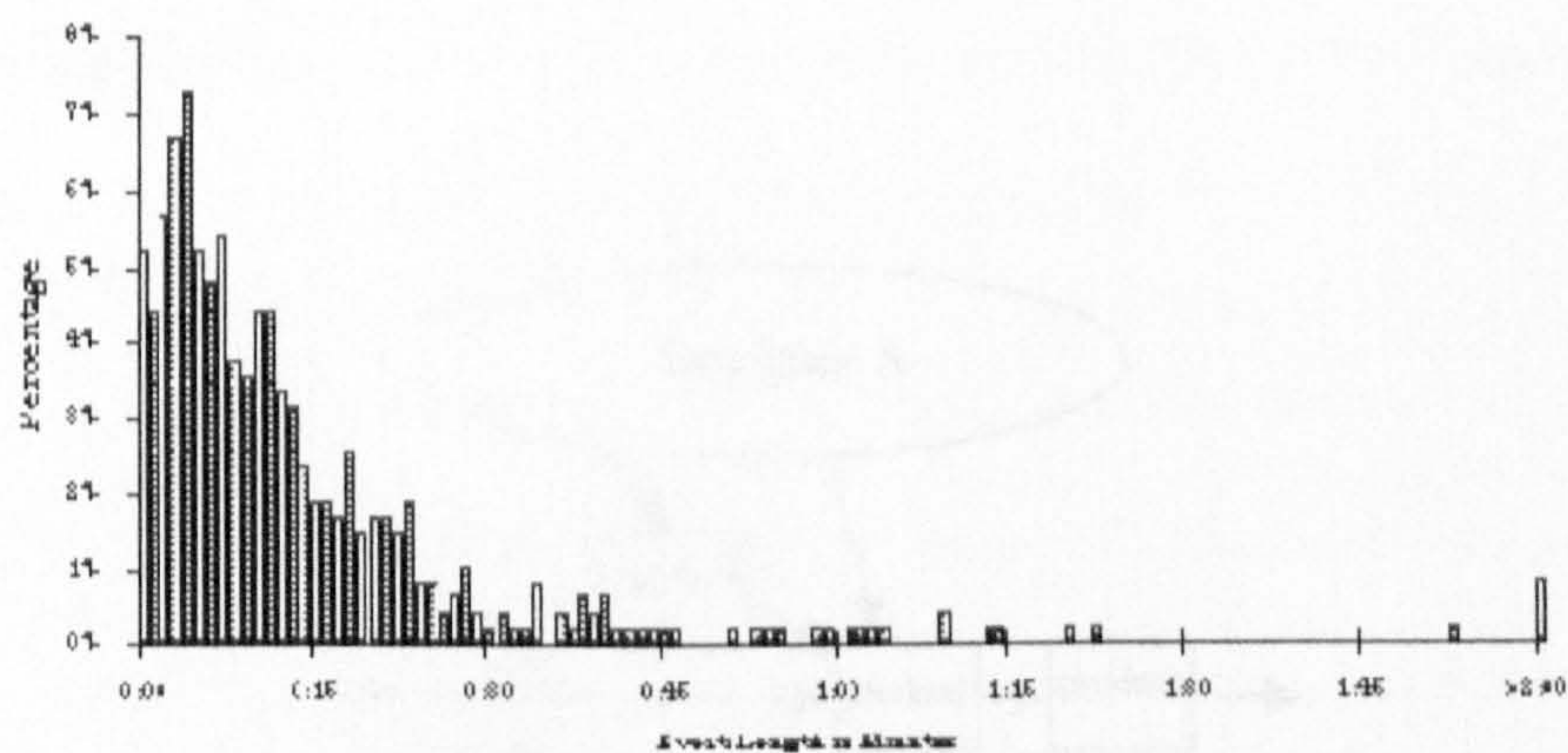
Examination of the activity shows that design is indeed a series of activities that are loosely structured and working at different levels of abstraction. In analysis of a pair of designers working together to design a bicycle pannier bag, Purcell, Gero, Edwards & McNeill (1996) found the designers moving cyclically through design, goal management and process planning activities. Likewise, Suwa & Tversky (1997) find that designers cycle through different modes of representation, from verbal to graphical, from conceptual to perceptual. The cyclical nature of design is therefore apparent.

How long are these cycles? In analysing a number of design activities of designers working individually at tasks lasting between one and two hours, Gero & McNeill (1998) have shown that design is in fact a process that consists of a series of distinct episodes that occupy discrete and measurable periods of time. An episode, in their definition, is a period in which the designer's intention is constant. When the intention changes, a new episode is started. The episodes allowed the designer to move between different design states, such as synthesising, analysing and evaluating. As they progressed, the designers cycled between the states rapidly.



The most significant finding in this research is that the temporal spans of design episodes are remarkably short. In one design analysis, they recorded the majority of episodes as taking less than 30 seconds; in another in which the participants were more expert in their field, most episode lengths were less than 15 seconds (see Figure 2). As the authors note:

“These differences may reflect differences in expertise with the experts moving quickly through the design task or they may reflect differences... between the designers.” (Gero & McNeill, 1998, p. 56)



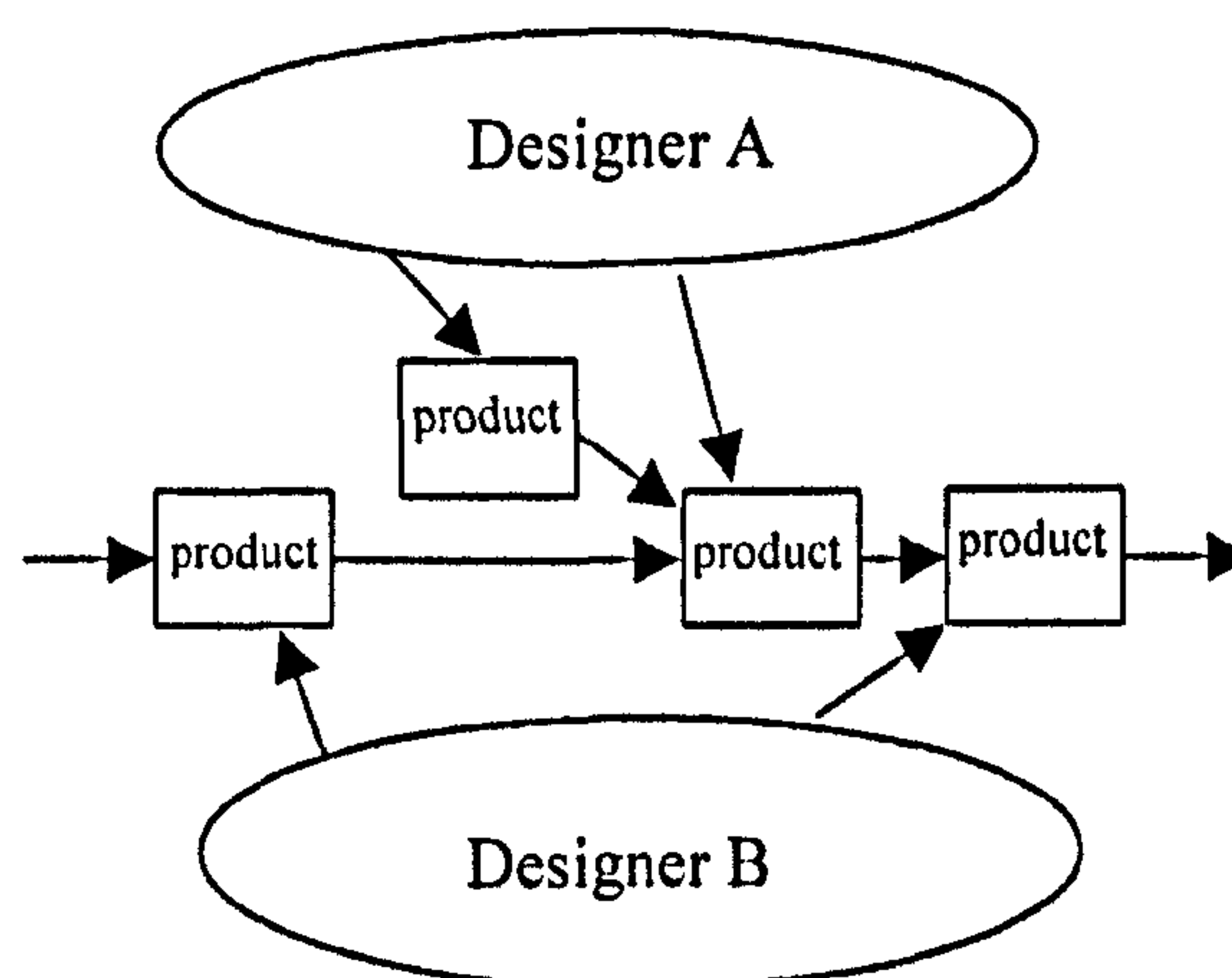
**Figure 3:** Event lengths during design  
(from Gero & McNeill, 1998)

Thus Gero and McNeill show that design can be seen as a series of discrete activities and that the level of expertise affects the way work is done, being discernible in the temporal pattern of their work. As collaborators come together in design, we can assume that the nature of their activity does not change since collaboration still requires a designer to attend to design as an individual as well as collaborate. Collaboration is probably episodic and cyclical too. This means that design remains a series of discrete steps. Collaborators work together for



moments, then divide up and go their separate ways (Klahr, 1998). The participants act as individual experts addressing design issues from their perspectives. Their expertise may change during a design session as their understanding is supplemented and they learn from their involvement.

These descriptions of collaboration tell us that the loose coupled model is probably correct. Each participant contributes what they can in different domains of expertise at moments when they have the knowledge appropriate to the situation (Figure 4).



**Figure 4:** Loose coupled design process

The loose coupled model of collaboration implies that we can segment the process into component parts, not only design steps such as plan optimisation but also task steps such as the goal management and process planning identified by Purcell, et al. This model is supported by comments from the client's perspective too. Blackmore (1990, p. 21), himself a client of several major architectural projects in

London, describes the benefits of a 'federalist' team structure as preventing any one participant gaining too much power.

We see too that the parts of the cyclical process will draw upon different representational modes (Suwa & Tversky, 1997). The cyclical period will be short (Gero & McNeill, 1998). It is likely then that collaboration will need to be supported by a variety of tools, not one, and that the users will need to move quickly between them as they change from one cyclical state to another. Lastly, we note that the expertise of the participants affects the cyclical nature of the work, with those more expert cycling faster than novices.

This model, however, does not help us understand the means by which the interactions take place and the determinants of beneficial collaboration. Appropriate configurations of CSCD systems depend upon an understanding of this communication and the impact that technology has on it. The discussion about collaboration is therefore concluded below by examining the roles of the participants collaboration. This is then followed by an examination of theories of design from which we can obtain an understanding of the content of the collaboration.

### **2.3.3 The contribution of roles**

We team together in design settings to take advantage of what Steiner 1972 calls *process gain*. Collaborative success can therefore be said to be achieved when we have accomplished something in a group which could not be accomplished by an



individual. Shea & Guzzo (1987) identify three facets of a task which determine the success of group effectiveness: task interdependence (how closely group members work together), outcome interdependence (whether, and how, group performance is rewarded), and potency (members' belief that the group can be effective). To be successful, a collaborative project must establish a definition of the team, identify their outcomes, ensure there is a purpose of the collaboration and clarify the interdependencies of the members.

If this is to be possible, are there limits to collaboration, either in time, place or size? Can we collaborate if we have too many or too few participants? While Steiner's work suggests strongly that the maximum number of participants in an effective working group is four, others have found successful collaboration extending to many more. Sudweeks & Rafaeli took part in an extensive and prolonged exchange with over one hundred scientists and concluded that collaboration was possible with large numbers (Sudweeks & Rafaeli, 1996). As noted by Abarbanel, Brechner & McNeeley (1997), the many thousands of Boeing engineers who worked on the 777 consider themselves collaborators. From these examples, it appears that there are no numerical limits to collaboration, nor physical, when taking place in computer-supported environments.

From their survey of studies in collaboration, Mattessich & Monsey (1992) identify six factors that influence the success of a collaborative effort and the characteristics that support successful collaboration. These factors can be summarised as:

- Environment, consisting of the geographic or social location of the group, with prior experience in collaboration among the group supporting success;
- Membership characteristics, that is, the skills, attitudes and opinions of the group members, with mutual respect, understanding and trust being important as is the inclusion of an appropriate cross-section of stakeholders;
- Process/structure, the management, decision-making and operational systems of the collaborative group, with success coming from a processes which allows members to share a stake in the process/outcome and multiple layers of decision making allowing participation;
- Communication, to keep participants informed, convey opinions to influence the group and to send and receive information, in particular engaging in open and frequent communication with issues being discussed openly;
- Purpose, stating clearly the reasons for the collaboration, defining the goals and specific tasks, delineating clear concrete attainable goals and objectives and building a shared vision; and
- Resources, the financial and human resources to ensure that the outcome can be met, in particular providing the group with a skilled convenor who can facilitate a collaboration with fairness and respect.

Of the characteristics of collaboration identified (Mattessich & Monsey, 1992, pp. 12-14), the most commonly identified with success are mutual respect and

trust, appropriate cross-section of members, open and frequent communication and adequate resources.

This list illustrates that collaboration is not formulaic but has to be constructed for the situation. It is a mix of factors which leads to successful collaboration, not particular facets. While it addresses collaboration in a wide variety of fields, not architectural design, this survey tells us that collaborative design must be considered not only in a technological sense but as a *process* too.

Since they do not focus on distal collaboration, Mattessich & Monsey do not address the role of technology as a means of communication but their model allows for it as an element in the resources. Likewise in their definition of environment they do not consider teams which are not collocated. In order to apply their structure to CSCD, we need to extend environment to include separated distal locations. This suggests that collaboration may depend on the multiple management of environments, not a singular consideration as for a collocated team. This means the responsibility for ensuring success is distributed, just as the task requiring the collaboration.

This process is supported by the participants. As Cuff (1991, p. 241) has pointed out, collaborative design is supported by individuals playing key roles in the process. Sonnenwald (1996) identifies five important roles to assist in successful collaboration. In her study of design processes in engineering and architectural practice, she finds that collaboration has to transcend organisational boundaries.



To make a multi-organisational collaboration succeed, she finds that thirteen roles exist:

- a *sponsor* to secure acceptance and funding for the project
- an *interorganisational star* to lead interactions with others in the larger organisational units and beyond to external organisations
- *intraorganisational stars* to transmit and filter information about goals, subgoals etc.
- *intergroup stars* to represent groups in design and task discussions
- *intragroup stars* to facilitate interactions within groups
- *intertask star* to facilitate interaction and negotiate conflict between people engaged in different tasks
- *intratask star* to co-ordinate and facilitate actions within a task
- *interdisciplinary star* to integrate knowledge from different disciplines and domains
- *intradisciplinary star* to transmit information about new developments within a discipline
- *interpersonal star* to facilitate interaction among individuals
- *mentor* to filter and transmit career information to individuals
- *environment scanner* to bring to the attention of participants external information which is relevant to the project
- *agent* to facilitate interaction among all participants (Sonnenwald, 1996, p. 290)

The roles outlined above concur with those set out by Mattessich & Monsey. Note the role of facilitation identified here. The importance of this role is spelled out in several studies (Mattessich & Monsey, 1992; McConnell, 1992; Shelden, et al., 1995; Sudweeks & Rafaeli, 1996; Sonnenwald, 1996). Sonnenwald is most specific the roles, in particular differentiating facilitation between groups (*inter...*) and among groups (*intra...*). A distinction needs to be made in terms of the duration of collaboration. Sonnenwald based her analysis the design and construction of a house as documented in Kidder, 1985 which lasted ten months.

Mattessich & Monsey refer to short term collaboration as well as long term. Reviewing Sonnenwald's list, we might conclude that some of the roles might be dropped for short-term collaboration. For example, the role of mentoring may not be project-based for a collaboration which lasts only a week, whereas roles of intergroup and intragroup communication could not be left out.

Sonnenwald notes that where one or more of these roles was missing, participants noted that the design process was less rewarding or satisfactory. Although the list appears to be excessive, an individual may assume more than one of the roles identified, hence the roles may not all be apparent on initial observation. When implementing computer-supported collaborative design teams, these roles should be kept in mind to facilitate success of projects.

It should be noted that Sonnenwald concludes that the skills for these roles are learned, not innate. Some roles are identified as requiring over eight years of experience to fill successfully. When Cuff notes that the key roles exhibit "talent and authority" (1991, p. 241) which is essential, Sonnenwald's research suggests that this talent is learned, hence it is an expertise which has been acquired (Bedard & Chi, 1992).

Collaboration is not easy and can fail for a variety of reasons. Sonnenwald (1996) introduces us to the concept of 'contested collaboration' in which participants bring with them their particular and unique perspectives on the problem, the process and the product. These perspectives can lead participants to 'contest'

contributions from other team members, resulting in conflict and negative outcomes in design or process quality.

### **2.3.4 Summary**

Collaborative design is a loose coupled process in which the participants work in a cyclical manner, contributing their expertise as and when it is needed. The sub-processes of collaboration may happen rapidly, at cycles of less than 15 seconds. Much of the work we carry out in 'collaboration' may be co-operation or co-ordination, requiring lower levels of participation or commitment.

Since collaboration is loose coupled, happens at different levels of participation and can happen rapidly, the role of the individuals must be understood. Successful collaboration depends upon clarity of roles within the process. Some roles are critical, such as key facilitators between or within groups, while others are useful. Successful collaboration depends upon a number of factors rather than a specific engagement in a particular process or technology.

To establish how collaborative design can occur, we now need to understand design more thoroughly. To this end, a review of design methods is presented.

## **2.4 Design methods**

In order to frame discussion about a particular design activity such as computer-supported collaborative design, we must know something of the design process itself. Deriving design process models has been the quest of design methods



research, specifically over that past three decades, with a considerable number of postulated models resulting. A brief overview is presented in this section and a framework for computer-supported design identified. Following this, we examine the theoretical frameworks which have been invoked in implementing CSCD, namely: design as a social activity, situated action and cognitive process models. At the end of the section a model is proposed by which to examine the nature of computer-supported design collaboration. This model is applied in Chapter 5 in an experimental analysis of computer-supported collaborative design.

### 2.4.1 The systems approach

Early design methods studies viewed design as a series of rational (Bazjanac, 1974) or prescriptive systems (Goel & Pirolli, 1992) based on a logical positivist heritage (Schön, 1983, p. 30). Design studies consisted of increasingly detailed analyses of activities within these systems. This logical positivist approach permits the belief that computers could be of use as discrete design tools which, if sufficient analysis was done, could automate the design process.

Typical of this approach is the paper "*Is automated architectural design possible?*" (Salvadori, 1974) in which the author suggests that architectural design can be divided into discrete processes within a sequence of five phases: programming; schematic; preliminary design; working documents; and construction. Salvadori continues that architectural design must accommodate "human-value judgements", but notes that since voting preferences can be computer modelled by mathematical analysis, so too can human value judgements

be modelled, including aesthetic judgements. Objective issues such as energy efficiency are easily handled. The author then concludes therefore that the automation of architectural design is not infeasible. The paper illustrates the typical weaknesses of this position, failing to explain how aesthetic or human-judgement values might be defined or gathered and then decomposed to fit statistical or mathematical manipulation.

A more sophisticated and rigorous exposition of the rational position is found in the problem-solving theories of Herbert Simon, particularly the problem solving aspects of design itself (Simon, 1969, reissued in a revised third edition in 1996 with a new chapter on complexity and with updated presentations of cognition and the science of design). In Simon's presentation, design is a process of describing a problem from an ill-defined beginning and seeking the bounded solution space within which to identify possible solutions by employing heuristic search techniques. That Simon's problem solving approach has been assimilated into the profession can be seen, for example, in the widely respected book on planning, "Problem Seeking" (Peña, 1977). We can also observe it as designers describe their design work, for example when designers identify six steps to completing a design project: "quantify problem; concepts; refine; evaluate design ideas; design; present" (Cross & Cross, 1995, p. 150).

This self-assured attitude to design was shaken with the introduction by Rittel of the idea that some design problems belonged to a class of problems he called "wicked". The term is first reported in Churchman (1967) and later developed in

Rittel (1972; 1973). Rittel identifies wicked problems as a "class of social system problems which are ill-formulated, where the information is confusing, where there are many clients and decisions makers with conflicting values, and where the ramifications in the whole system are thoroughly confusing... where proposed 'solutions' often turn out to be worse than the symptoms" (Churchman, 1967, p. B141). Such problems cannot be solved by a rational or prescriptive approach.

The idea of "wicked problems" encouraged a rethinking of design processes and a recasting of their methods in a different light. According to Bazjanac (1974), the move is from design as subsystems to design as argumentation. Argumentation was the exposition of views from all involved and enlightenment of the priorities of the problem. The problem, as Buchanan (1995, p. 19) observes, is that each participant has their own position from which to argue as well as different modes of argumentation and these can be irreconcilable. These differences have left different professions which are meant to work together in fundamental and often bitter opposition.

There are those who do not see wicked problems as defeating a problem solving approach to design. For example, Goel articulates a similar theory of problem spaces as Simon (Goel & Pirolli, 1992; Goel, 1995). Starting with a definition of design based on work by Newell & Simon (1972) and Reitman (1964), Goel divides design problems into well-structured and ill-structured, the solution of only the latter qualifying as 'design' in his terms. He then proceeds to explain how ill-structured problems can be solved by a rational hierarchical approach, moving



from problem structuring through preliminary design to refinement and detailed design (Goel, 1995, p.123). Solution to design problems is through decomposition into modular problems. A review of his definition of the conditions of ill-structured problems (Goel, 1995, pp. 91-93) shows that it is very similar to Rittel's ten properties of wicked problems:

1. There is no definitive formulation of a wicked problem
2. Wicked problems have no stopping rule
3. Solutions to wicked problems are not true-false but good-bad
4. There is no immediate and no ultimate test of a solution to a wicked problem
5. Every solution to a wicked problem is a 'one-shot operation'; because there is no opportunity to learn by trial-and-error, every attempt counts significantly
6. Wicked problems do not have an enumerable (or exhaustively describable) set of potential solutions, nor is there a well-described set of permissible operations that may be incorporated into the plan
7. Every wicked problem is essentially unique
8. Every wicked problem can be considered to be a symptom of another problem
9. The existence of a discrepancy representing a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the problem's resolution
10. The planner has no right to be wrong (Rittel & Webber, 1973)

Goel therefore postulates a means by which wicked problems can be addressed and resolutions found using the logical positivist approach.

### **2.4.2 The reflective approach**

The logical positivist approach to design has not found favour in design teaching or collaborative design research. The model of design which appears to have widespread acceptance among those studying collaborative design is that set forth by Schön, that design is a 'reflective' process, specifically that design is engaged through "reflection in action" (Schön, 1983; Schön, 1987). Schön introduces his argument by contrasting himself to Simon's approach, noting that the limitations

of the logical positivist model of design, what he calls "Technical Rationality", become apparent as formal modelling diverges increasingly with real-world problems (Schön, 1983, p. 44). Instead, he proposes

"an epistemology of practice implicit in the artistic, intuitive processes which some practitioners do bring to situations of uncertainty, instability, uniqueness, and value conflict." (Schön, 1983, p. 49).

In this model, Schön sees design as a "reflective conversation with the situation" (1983, p. 76). Schön suggests that it is through a process of reformulating the problem as it is encountered that design problems are solved. The good designer is able to identify "the problem of this problem" and, through working with it, he "reappreciates, reinvents and redraws the problem (1983, p. 104).

We can use Schön as the counterpoint to the rationalist position. It is possible then to examine the two positions, rational design and reflection in action, and identify their value as design strategies. This has been done by Dorst and Dijkhuis who conclude:

Describing design as a rational problem solving process is particularly apt in situations where the problem is fairly clear-cut, and the designer has strategies that he/she can follow while solving them... Describing design as a process of reflection-in-action works particularly well in the conceptual stages of the design process, where the designer has no standard strategies to follow and is proposing and trying out problem/solution structures. (Dorst & Dijkhuis, 1995, p. 274)

These models inform us as to the ways in which design can be supported and can suggest an approach to defining tools for CSCD. If design is considered in the positivist rational framework, design systems need to provide distinct and articulated problem solving tools. Design itself can be automated by implementing discrete software systems to handle each design problem. If, on the other hand,

design is considered to be a process with exploration through an unprescribed series of indeterminate actions, the tools to support design will be less articulated and more supportive of a variety of processes. If, too, collaborative design is a group process of unstructured reflection, the demands on communication channels may be greater than if design is regarded as distinct articulated processes.

Before we leave the discussion of design theories, we must note that Schön's model fails to explain several key issues about design, not least of which is to explain how exactly this 'conversation' takes place and how the conversation then informs the designer and influences future actions.

In a review of theories of professional knowledge and their implications for developing professional competence, Michael Eraut (1994) discusses the theories of Schön in the context of other theories of professional development, namely Hammond's Cognitive Continuum Theory (Hammond, 1980) and the Dreyfus brothers' model of skill acquisition (Dreyfus & Dreyfus, 1986). He notes that Schön's framing of the problem of design is based on selective observation of designers at work, ignoring all rational examples of work process and lighting on only the artistic intuition (Eraut, 1994, p. 143). Thus the reflective process is emphasised at the expense of a deliberative problem solving approach. This selective discussion of design leaves us with a particular focus on the actions of design and ignores what Eraut calls the deliberative process by which theory and action are understood by a professional (Eraut, 1994, p. 149). He suggests that Schön's theory is one of metacognition during a skilled behaviour, a theory of



action and not a theory of reflection. The process of metacognition is that in which the architect is "alerted to a problem, rapidly reads the situation, decides what to do and proceeds in a state of continued alertness" (Eraut, 1994, p. 145).

Eraut also notes that Schön and Hammond fail to account for the factor of time (p. 149). On occasion a professional is challenged to solve a problem when there are no time constraints. Most often, however, the professional is acting under significant time constraints and has to act at speed. To this end, he proposes a relationship between speed and mode of cognition (Table 2). The last row represents Schön's contribution. The common interpretation of Schön's work then falls into the middle column, that of rapid interpretation and its emphasis on action.

Table 2. The link between speed and mode of cognition (from Eraut 1994)

	Speed		
Analysis	Instant recognition	Rapid interpretation	Deliberative analysis
Decision	Instant response	Rapid decisions	Deliberative decisions
Action	Routinised unreflective action	Action monitored by reflection	Action followed by a period of deliberation

The focus on rapid interpretation and interaction with the context leads us to reconsider design as a *conversation* with the context, to use Schön's term. There are times when the converstaion simply cannot take place, there is not time. At



other times, the conversation is more extended that it ceases to be a conversation but is a musing, a deliberation.

### **2.4.3 Summary**

In the review above, we have seen that design methods lead us to view architectural design in two ways: a systems approach in which design tools can take over aspects of designing, or a reflective approach for which the tools needed will be non-intrusive support but not tools to take over design actions. We can conclude that design can be understood usefully as both and that both types of tools are needed.

An implication of the reflective approach is that the conversation which is design must be shared by all members of the design team to different degrees in a collaboration. The implication of this is that design is a social and situated act in which successful design will only result if the context and conversation are widely shared. The configuration of many VDSs suggests that this assumption is widely held. The following sections therefore examine the proposition that design is social and situated. A third position is examined to, that design is an expert action in which collaboration can be understood using a cognitive model.

## **2.5 Models of collaborative design**

The design methods presented above do not examine architectural design as a collaborative activity. There are three ways in which this can be presented: design

as a social act (Cross & Cross, 1995), design as a situated act (Gero, 1998) or design as a cognitive act (Kvan, Vera & West, 1997). Each of these interpretations is examined and the implications for CSCD established.

### **2.5.1 Architectural design as a social activity**

Mitchell (1994) has observed that computer tools to support design have made a shift from serving as problem-solving tools, to knowledge-based systems in support of design as such and are now poised to act as tools to support design as a social activity. This depiction of the changing role of CAD follows closely the change in architectural theories set out above, from logical positivist frameworks, through systems approaches to the prevailing attitude today of collaborative design and practice as a situated and social activity (Coyne, et al., 1996, p. 546).

Others, studying the actions of designers, observe interaction and conclude that the presence of certain categories of interaction constitutes a social act. For example, Cross & Cross identify six design activities during design by which they define design as social action:

- Defining roles and relationships
- Planning and acting
- Information gathering and sharing
- Problem analysing and understanding
- Concept generating and adopting
- Conflict avoidance and resolution (Cross & Cross, 1995, p. 144)

Their conclusion is that design is a social activity if these sub-activities are observed. This is an insufficient definition of social, however, as Mitchell

illustrates when he extends his portrayal of the social nature of design to include not only a social network of humans working together but also a supporting cast of software agents providing specific knowledge and problem-solving capabilities to the team. Indeed, the software agents described by Fruchter, Clayton, Krawinkler, Kunz & Teicholz (1996) and Kalay (1997) engage in these activities and therefore be said to engage in social activity.

From these uses of the phrase, we can see that the statement that "design is a social activity" is broad but ill defined and demands a closer examination in the context of architecture and architectural practice. Kostoff (1977) documents the role of the architect through history, orchestrating and co-ordinating the construction of edifices in different cultures and ages, all of which require collaboration. Today, the collaborators are often separated by discipline as well as distance, each with its own representational techniques as well as each wanting to work on their own version of the documents. A set of documentation for a design project today typically contains such a density of information that separation by discipline or other classification is a norm. From this, we can draw a distinction between two meanings of 'social'; in one, social refers to the communal context of the work carried out, in the other it refers to the situational context. The discussion below then will focus first on the communal context and then on the situated context.

Professional architects work within a context of the profession and its players. In this study of the work of scientists, Latour describes in great detail how

“(m)achines are drawn, written, argued and calculated before being built” (Latour, 1987). He notes that the machines have their origins in a network of people of many kinds and they function only within an extended network. This network not only serves to create the machine but also shares in the knowledge which gave rise to the artefact and supports its application and use after creation. Kuhn (1970, p. 210) goes further and says that knowledge is “intrinsically the common property of a group or else nothing at all.”

Latour claims that “(o)f all the parts of technoscience, the engineers’ drawings and the organisation and management of the traces generated simultaneously by engineers, draughtsmen, physicists, economists, accountants, marketing agents and managers are the most revealing. They are the ones where the distinctions between science, technology, economics and society are the most absurd.” Surely the same applies to the architect’s drawings. The drawings and traces created between the architect and the other participants such as noted by Kostoff (1977) and Cuff (1991) can be considered a technoscience. It is no less absurd then to make distinctions between the various professions or the fields of knowledge involved in the creation of buildings than in the creation of machines. Both are artefacts created by participants integral to a network.

The knowledge required to produce an architectural design lies beyond the realm of one individual. Deriving a solution to an architectural design problem draws upon the collective knowledge of the group, the team, gathered for the project. Hence the cognitive effort required to assemble the solution is a collective effort.



The knowledge required can therefore be described as the knowledge of the social group working on the problem and the cognitive effort "social cognition" (Hutchins, 1991) or "distributed cognition" (Zhang & Norman, 1994).

In this sense, *design is social* in that design draws upon a *network of knowledge*. Social knowledge exists within the network of participants but not within any one participant. Thus, the knowledge exists only if and when the supporting society exists and it changes as participants of the society change. In this respect, design is social.

By social, however, we typically mean more than being a participant in a network of knowledge. There are implications that the participant interacts with other people involved in the design process, that common concerns are explored and that social conventions are mutually subscribed. How do these aspects of 'social' affect design? Is it through the network to which Latour refers? What makes such a network function? As Latour notes, "the word network indicates that resources are concentrated in a few places – the knots and the nodes – which are connected with one another – the links and the mesh: these connections transform the scattered resources into a net that may seem to extend everywhere." In the design of buildings, the architect's office is one such node where resources are concentrated. Other nodes are the client, financing sources, regulatory authorities, other professional consultants, etc.

The notion of a node makes clear the reciprocal nature of the activity of designing. There is no moment in the process where the information and decisions from all the other nodes are of no importance, even if there is no continuous overt inflow from them all. Similarly, the work within the architect's office is modelled with nodes and networks of participants responsible for different aspects of the practice and projects. The resources of an architectural practice which are brought to bear on a project include information from others in the network, within and without the office, as expressed in documents received or communications exchanged (the "traces" to which Latour refers) but also includes previous experiences, memory of earlier work executed by each individual as well as the corporate memories available, the traditions both verbal and non-verbal. All of these traces may be formalised to different degrees.

The activities of an architectural office are many, but the centre of attention is the production of buildings. The office structure may vary; using the Superpositioning model established in Coxe, et al. (1987), for example, we can distinguish three attitudes (Coxe, et al. call these 'technologies' but we will avoid that term here for the sake of clarity). The model identifies those practices which focus on the *delivery* of projects; those concerned about the provision of *services*; and those for whom the generation of *ideas* is paramount. For each of these three types we can describe administrative and creative structures which assist in the accomplishment of the essential goal of building design. Describing these according to the model of networks, we see in *delivery* practices nets which are linear with work directed

centrally and individuals processing sequentially, each person in the office occupying a well defined role in which work is repetitively executed. *Service* practices form elaborate networks within the office as individuals take on many roles at different phases of projects. *Idea* practices form meshes supporting the creative individuals central to the success of the firm. The three types of networks illustrated by the Superpositioning model are therefore chain-like, pyramidal and radial.

Design may also be considered in terms of a dramaturgical model. Each member plays a certain role in the unfolding play. Each actor has a 'script' of a particular nature, containing both episodes worked out in great detail and episodes where only the barest outline of the plot is available, as in experimental plays on the stage. Here, as there, we have a list of players and their roles, perhaps (but probably not) described accurately by their titles. As often as not, the individual player is left to deduce the script of the other players from their actions and communications. Roles consist of rules for the actions of individual actors, but it is important to understand that rules are not causes of the behaviour of the individuals, forming merely a repertoire of the possibilities for action. Each player is ultimately responsible for the manner in which he or she chooses to use the set of rules (Harré, 1993, p. 181).

Whatever the structure of the office or project team, it would appear that the design originates with an individual. These initial design actions (drawing, talking, modelling) gain meaning by being part of an act (Harré, 1993) embedded

in the relational framework of commitments and expectations, in the net making up the social world of the architect. This net is of course in turn related to the other social worlds within which the architect participates. The act/action schema is imbedded in language sequences and the pencil movements or gestures which are used during communication are part of this schema. Any one act can be carried out by a variety of actions and the actions obtain their meaning within the context of the act itself. The act is indeed dependent on the wider context of the participants and the project. Thus, design is social in as far as any architectural design today exists only within a complex setting of roles and participants.

In both respects that design is social mentioned so far — social knowledge and social action — the success of the participation is in good part dependent upon the extent to which the participants have adapted to each other's worlds. Socialisation of course is something which starts early in life, but we can trace it too through the training and professional practice of an architect. At the broader level, it takes place during the "student/master" symbiotic relationship, whether at a school of architecture or within an office. It can be found during projects in the relationship between the participants, where some are leading and others following. Indeed, the relationship between the architect and the client can only be successful if it passes through a process of adaptation and mutual acquaintance. This process, reported by the American Institute of Architects as being critical to a successful project, has been termed the "educating the client" (Franklin, 1989, p. 46) and "cementing the relationship" (Coxe, 1989, p. 93).



What occurs in this process of mutual acquaintance? The participants are learning each other's language, identifying and resolving perceptual differences, arriving at common ground. Kuhn (1970) describes the process and effect of successfully identifying such common perceptions which he refers to as 'paradigms'. Thus the socialisation that occurs during design is also important for a successful resolution and outcome to the project.

While we have argued that design must involve a network of participants in Latour's terms, not all designers participate in the same way. There are many who participate as individuals, working alone for crucial periods and then returning to the network process. As reported by Lawson (1994, p. 36), for example, Herman Hertzberger works alone on his A3 drawings which he then brings to the design team for development without his continuing participation. There are many others who maintain offices of one person, or as close to one as they can manage, because they receive greater satisfaction and better control over the projects in that way. Some succeed in maintaining small offices by contracting out discrete portions of the work, such as drafting or specifying. As we have noted above, collaboration can occur as loose coupled or close coupled. The goal of tools for collaborative design should recognise this and not impose a single method of collaboration.

The issues of collaborative practice have received considerable attention in professional practice in the past years, as clients and professionals try to reduce the wastefulness and litigious aspects of construction. A number of techniques

have been used to improve the experience in projects and to improve collaboration between participants, including the technique of partnering. It is instructive to consider the experience of these forms and their goals. A comprehensive view of the project context can be found in project partnering (Larson, 1997). Larson concludes that partnering does lead to more productive teamwork and better projects. The principles he identifies are:

- Team building sessions: building a collaborative relationship between key people before the project starts
- Conflict identification: before the project starts identify potential conflicts and problems
- Problem solving process established before project starts
- External consultants used to facilitate the relationships between key participants
- Joint project charter states agreed objectives and responsibilities
- Fair profit is assumed to be a valid part of the contract
- Provisions are made for continuous improvement

Larson notes that the success arises from a comprehensive application of partnering principles, not any particular principle alone. They attempt to bring the participants together early in projects, not later. A typical means of applying these principles in the design professions is described by Allbriton & Smith in their outline of the steps a team might take if they are collocated. To date no results have been published on the feasibility or efficacy of distal partnering.

“Typical (partnering) steps include:

- Introductions (if necessary), to bring everyone up to speed on others' roles.
- Personal style awareness, to provide participants with better understanding about how others function, particularly in the context of the project and the steps necessary for completion.
- Stakeholder discussion, where participants explain their respective constituencies, and the issues of importance to them. From individual goals, the participants will evolve a common mission and common goals for the overall program, generally expressed in a "charter."
- "Pressure point analysis," in which participants share and discuss their views on those aspects of the project that are likely to warrant special attention.
- Group effectiveness discussions regarding how to have successful meetings related to the various kinds of issues that are likely to arise, particularly around "pressure points."
- Partnering Reinforcement/Monitoring Plan, to develop a schedule and procedure for looking periodically at the overall project process to assure that the necessary behaviors are continued and the benefits of partnering (skills) are maintained.” (Allbriton & Smith, 1996)

Note that these six steps include establishing social roles, identifying social knowledge and formally allowing for the socialisation process.

From the discussion above, we have identified three distinct implications of the term ‘social’:

- emergence of a collective body of knowledge known as *social knowledge*
- the dramaturgical interactions of the participants known as their *social roles*
- the process of identifying and subscribing to common work models and terms, known as *socialisation*

When establishing computer environments for distal collaborative design projects, we need to consider each of these three aspects. Each can be accommodated by different technologies, individually or in common. The context of knowledge is



brought together by providing tools for conveying components of the knowledge. The experience of partnering can help us understand ways in which the roles can be defined to improve the success of a project. From the analysis above, we can conclude that socialisation in the sense of an establishment and participation in a communal activity can occur by a variety of tools. Recognising that there are these three different aspects to the concept of social participation, we can set up process techniques and tools to deal with each, rather than trying to cope with all three concurrently using wide band-width video and audio to recreate face-to-face environments.

### **2.5.2 Architectural design as a situated activity**

In 1987, Lucy Suchman posed a question that reframed the work of cognitive science. Paraphrasing the question into the context of this thesis, she asked “how do you design – by plan or in response to the situation?” That is, is design a situated activity (Suchman, 1987) or is it a planned activity (Newell & Simon, 1972)?

The two approaches to describing the activities of design map well onto design theory – design as a planned activity maps on to the theories of design as a rational logical positivist process (Jones, 1966a; Jones, 1966b); design as a situated activity maps onto design as a social activity (Alexander, 1968). This mapping reflects too on the models discussed above by Dorst & Dijkhuis (1995): the rational design models of Simon (1996) and those framed as reflection-in-action as put forward by Schön (1983).

Situated action is not easily defined and its position in relation to more 'traditional' symbolic representations of cognitive processing difficult to pin down. A complete issue of Cognitive Science (Volume 17, Number 1, 1993) is devoted by the debate. As noted in Vera & Simon (1993, p. 80), the writings of situated action theory contain a wide range of views, some of which are "often incommensurate".

For the purposes of this discussion, I will use a working definition of *situated cognition* as set forth by Olson:

*Situated cognition or situated action* is the belief that an adequate description of cognition or intellectual activity must include details of how such activity is situated in its physical, social, cultural and historical environment. This view stresses the dominant role of these kinds of contextual factors and, as such, contrasts with the more traditional absolutist views of cognition that stress the role of universal principles of internal mental functioning. (Olson, 1994, p. 971)

As Olson continues, the contrasting position is that of modern cognitive theories:

...modern cognitive... theories have all attempted to explicate the internal mental representations and processes that underlie cognitive activity... Dominant questions have included the nature of internal representations (e.g. verbal versus imaginal, procedural versus declarative), the organization of internal processing stages (e.g., serial versus parallel, automatic versus controlled, implicit versus explicit), and the general architecture of the internal cognitive systems. The goal has been to characterize the universal, context-independent characteristics of the mind. (Olson, 1994, p. 971)

In this research, we are not looking to create artificially intelligent design systems for remote collaboration but instead look to investigate the effects of computer technologies in communication. Thus the goal in CSCD is not the same goal as that articulated by Suchman for research in machine intelligence:

Theoretically, the goal of (research on machine intelligence) is a computational model of behavior that not only, given some input, produces the right output behavior, but that it does so by simulating human cognitive processes. (Suchman, 1993, p. 2)

Suchman illustrates the distinction between operating with planned actions and engaging in situated action with a story of a fisherman from Truk (1987, p. vii). She describes a journey of the fisherman to places beyond the horizon in which the fisherman does not follow a pre-planned route but journeys from event to event. She draws a distinction between this Trukese fisherman, who knows his objective but has no path to follow to achieve it, with a European navigator who works to a plan which suffers when realities of weather and currents force deviations. The Trukese, she states, is successful not because they have charts from which they have produced a navigation plan for the journey, but because they have obtained from the surroundings information which guides them to their destination.

Suchman seems to ignore the means by which that the Trukese fisherman is inducted to the art of navigation through years of childhood training. Lewis (1972) describes the lengthy and rigorous education children receive in navigation using models, drawings and outings on the seas. Not all the learning is through actions of doing or sailing. Much of the learning is abstracted and theoretical, using models and selective representations of natural elements. Through these various modes, the art of navigating by sun, stars, land forms, cloud patterns, the behaviour of birds and the patterns of sea swells are learned. The fisherman can therefore navigate by observing the conditions of the sea and aim their vessel from one point to another. The process of learning he describes is not unlike the training of a chess player (Chase & Simon, 1973) or artist (Hayes, 1985). This act



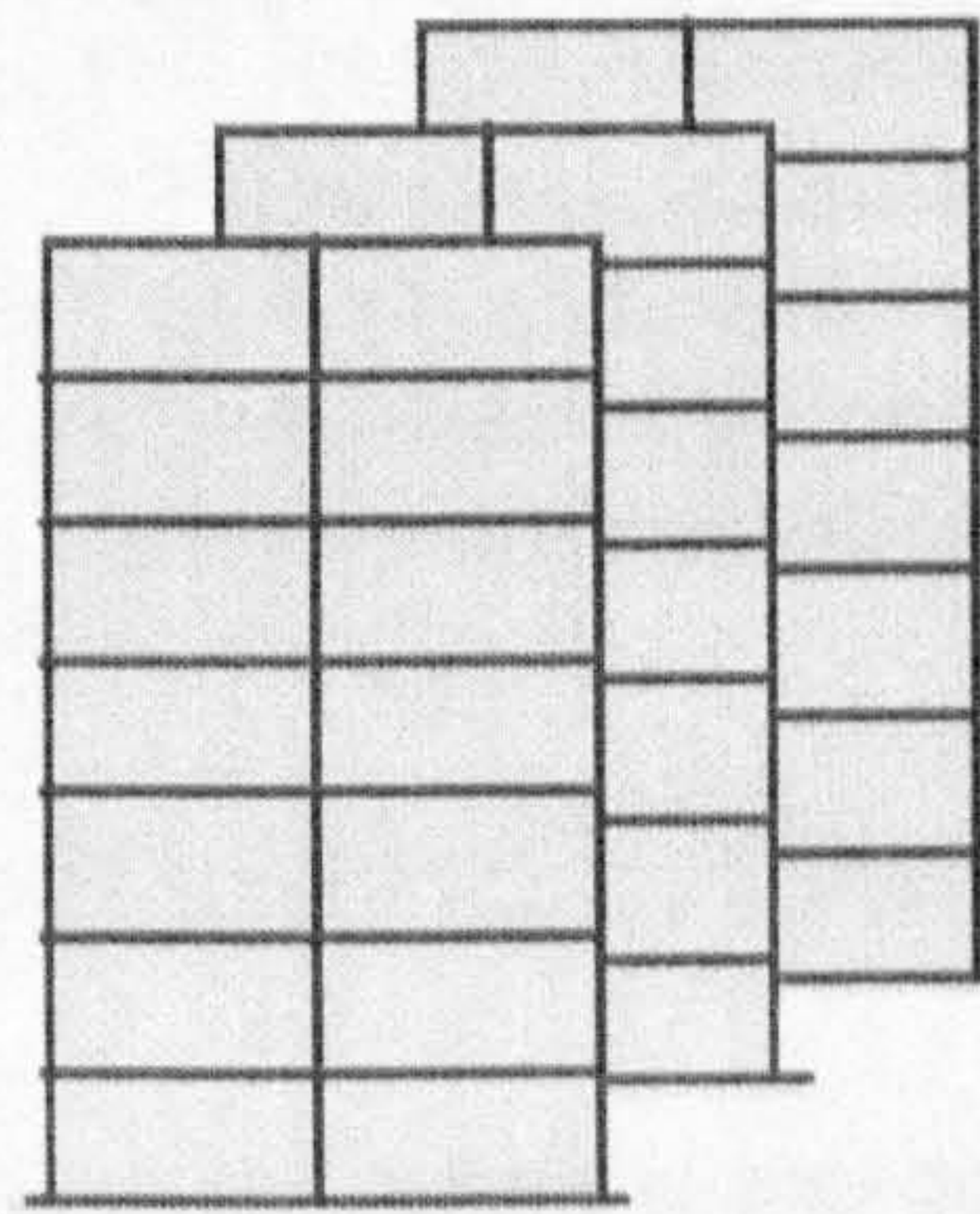
of navigation is not unlike that of an Occidental navigator who would not sail the seas oblivious of the conditions. The difference is that the Occidental has media by which the knowledge of the navigational elements can be made explicit. The Trukese has to learn these on shore as they have no medium to carry it with them at sea, other than memory. Indeed, Hutchins (1990) has examined navigation in a collaborative environment of piloting a large ship using modern navigational equipment and records the role of tools in this act. His observations do not support the notion of navigation as an enactment of a set plan but the result of a team adapting to their setting through intensive application of tools, knowledge and cognitive actions. In so acting, however, they are using their training from abstracted situations to derive a series of actions by which to sail to their destination. Navigation in this example is an expert action, not situated, nor is it a set plan prepared before embarkation.

Drawing a parallel in architectural design, let us consider an architect. She does not come to the problem unskilled, no matter the level of experience she actually holds. As such, the architect is not a novice. Suchman seems to argue that the contrast is not one between a novice and an expert (Suchman, 1987, p. viii); both navigators are experts. How then do designers solve the problem at hand? Like the Trukese fisherman, the skilled architect approaches a design problem with no fixed plan but, as with the fisherman, this does not imply she comes to the problem uninformed.



A typical interpretation of the theories of situated action in the world of design is illustrated by Gero (1998). In this paper, the Gero postulates that a series of sequential acts in design are guided by the results of previous steps, by what has gone before. As such, he concludes, the act of designing is situated. The example Gero uses to illustrate the notion that conceptual design is a situated act is as follows:

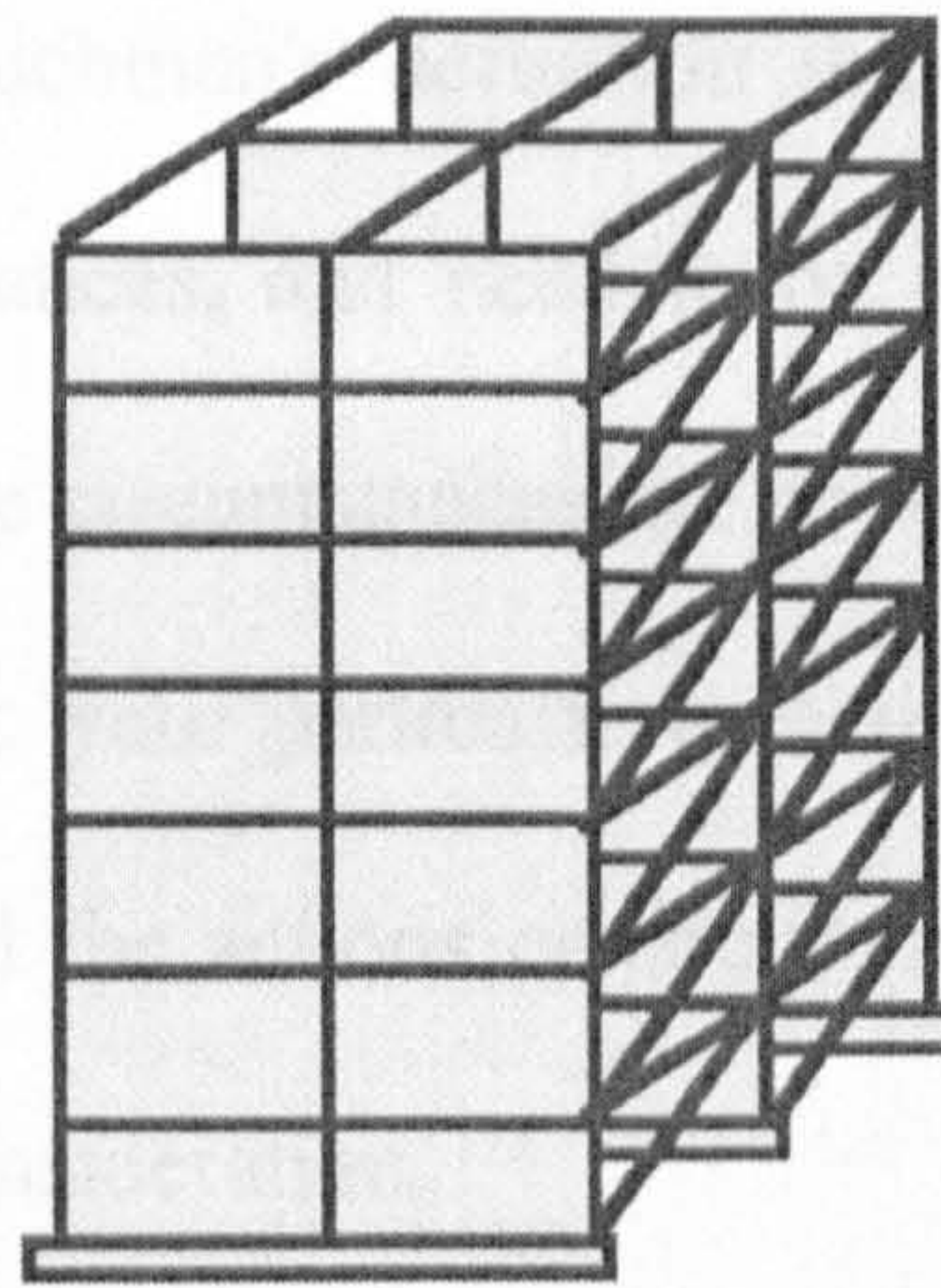
Consider now a structural engineer designing the framing for a tall building. The engineer commences with a series of parallel two-dimensional frames, Figure (5). With these frames the engineer is carrying the wind load from the primary wind direction. As a consequence of the way the engineer sees these frames he designs and analyses them as two-dimensional frames.



**Figure 5:** The structural engineering component of a multistorey building being synthesised as a series of two-dimensional parallel frames (from Gero, 1998)

After the primary frames have been synthesised and the member properties determined, the engineer now attends to the lateral bracing by placing bracing beams at each floor connecting congruent joints of adjacent frames, Figure (6).





**Figure 6:** Lateral bracing put in place by the engineer between the parallel two-dimensional frames (from Gero, 1998)

However, as the engineer inserts the bracing, he notices that the bracing produces a frame at right angles to the main frames and he decides to use the bracing as a frame. Further, having decided that there are now two sets of frames at right angles to each other, he notices that the external frames can now be viewed as the facades of a tube building... As a consequence he examines the possibility of redesigning the entire lateral and vertical loadbearing system as a tube structure. This clearly has involved a re-representation of the wind bracing from bracing to lateral frames. Then, from the original frames and these lateral frames a tube structure emerges. (Gero, 1998, pp. 9-10)

Gero bases this interpretation on his reading of Clancey (1997):

Situatedness holds that "where you are when you do what you do matters". (Gero, 1998, p. 4)

This definition of situatedness is in fact counter to what Clancey holds as situated action:

Unfortunately, the overwhelming use of the term *situated* in AI research since the 1980s has reduced its meaning from something conceptual in form and social in content to merely "interactive" or "located in some time and place." (Clancey, 1997, p. 23, italics original)

But Clancey's own definition is broader:

Every human thought and action is adapted to the environment, that is, *situated*, because what people *perceive*, how they *conceive of their activity*, and what they *physically do* develop together. (1997, pp. 1-2, italics original)



This is sympathetic with Suchman's definition that "actions are structured in relation to specific circumstances, and need to be understood in those terms." (Suchman, 1993, p. 75) These circumstances are not only where you are, but also with whom you are working, your particular perception of where you are, your intentions for the actions and the actions or circumstances which have preceded the particular action under consideration.

Situated cognition is both a theory about *mechanism* (intellectual skills are also perceptual motor skills) and a theory about *content* (human activity is, first and foremost, organized by conceptualizing the self as a participant-actor, and this is always with respect to communities of practice). (Clancey, 1997, p. 28, italics original)

As Suchman notes, the distinction between situated action theory and cognitive theory is that, in the former, the plans arise from the situation and are not taken from a store of predetermined responses. This is the central argument between the situated and cognitive positions. It is beyond the scope of this thesis to review or resolve the differences, if indeed such a goal is either necessary or possible. Instead, we can use the example given by Gero as a typical example of a situated design act to understand the implications of this theory for design and for CSCD.

Recognising the weakness of the situated position as stated by Suchman and Clancey, Gero qualifies his statement that design is situated by incorporating Dewey's (1896) statement that "Sequences of acts are composed such that subsequent experiences categorise and hence give meaning to what was experienced before." Thus Gero postulates that the engineer comes to recognise a tube structure as a result of the previous steps in the design process. This is to say

that design is dependent upon constructed memory — the engineer in the example is reconstructing his understanding of the design problem through the situation (although his example is not explicit about this aspect of the design process). The contention is that, as the engineer recognises the formulation of the problem as a tube, he is seeing the design problem in a new light and reinterprets all prior evidence in this new light. He is, implies Gero, reconstructing the problem from the situation. Gero likens this to Schön's observation that design is a "conversation with the medium". While the observation is accurate in that the designer is interacting and affected by the context, the situation, it is inaccurate in that the designer cannot be said to be reconstructing their complete professional knowledge base, to the extent of reinventing the engineering principles of a tube structure. The training and declarative knowledge base of the engineer is still the dominant determinant of the design process. It is accurate to say that design is influenced by the situation, but not to say it is situated, implying that the determinant factor in design is the situation.

An alternative interpretation of this design action is that this example does not illustrate situated action but instead shows the application of a set of expert knowledge which the engineer has acquired through training. Whether the designing is done in an office or an aeroplane, in Africa or Australia, will not affect the outcome, given that the building is for the same site and the designer is the same person. The ability to recognise the tube structure arises from the body of particular structural expertise held by the engineer, not his situation. A better

engineer will recognise opportunities and alternatives faster than a novice. The professional knowledge and experience of the engineer will inform the choice from the alternative structural systems, but the experience does not constitute a situated act. The drawings, which constitute the situation for Gero, are external representations providing information that is then perceived by the designer.

It is a short leap from the statement that "design is a reflective conversation with a situation" (Schön, 1983, p. 176) to conclude that design is therefore a situated act. But further analysis of Schön's discussion of Quist and Petra's activities illustrate that Schön himself is using the term in a loose fashion. He notes that Quist is able to lead Petra because of his mastery of the act of design, zeroing in on fundamental schemes and decisions, able to identify the problem itself. "Like a chess master who develops a feeling for the constraints and potentials of certain configurations of pieces on the board, Quist seems to have developed a feeling for the kind of conversation which this design situation sets in motion." (Schön, 1983, p. 104). As Chase and Simon (1973) have convincingly demonstrated, the chess master does not arrive at this ease and feeling through reaction to the situation but through extensive practice and acquisition of 'chunks' of knowledge (Miller, 1956, p. 93; Simon, 1979, p. 50) which are ready to be applied when needed.

We must recognise, on the other hand, that expert or declarative knowledge is not applied blindly as design proposals are made. But neither is it applied in a completely reactive, structureless fashion. It would be considered unprofessional to simply take designs from one project and apply them to another, without



careful evaluation of the implications of its use. At the same time, it is clear that some elements of design, such as design strategies, task planning and structure, do get carried from one project to the next. That we can call a body of architectural work a "style" or a "school" demonstrates this notion. Thus the expertise is interpreted and transformed. Schön's reflection process does not capture the nature of the activity either. Quist is not simply holding a conversation with the material at hand in order to identify the next step or the solution. As Schön notes, Quist is "masterful", working with unfailing "virtuosity" (Schön, 1983, p. 104). This mastery was acquired over time, not just at that moment. How was that mastery acquired? We can assume that mastery can be defined by knowledge and expertise — the greater the level of expertise, the more readily the practitioner is considered a master.

As Eraut (1994, p. 149) notes, experience is processed into knowledge through the process of deliberation carried out separate from the period of action. Examining the nature of professional work, Eraut introduces the notion of a "performance period", a time period of some length such as between lunch and tea break. In a performance period the professional carries out a series of tasks with focus, even if the tasks have no connection with one another apart from competing for the professional's attention.

The generic model of a performance period (Figure 7) ... is characterised by a context, a beginning and an ending, by conditions (which may change during the course of the period) and by a developing situation. Plans may pre-exist on paper or in the practitioner's mind, they may be developed or modified during an initiation period; or the practitioner may simply decide to handle the situation in a routine way or even to improvise. (1994, p. 150)

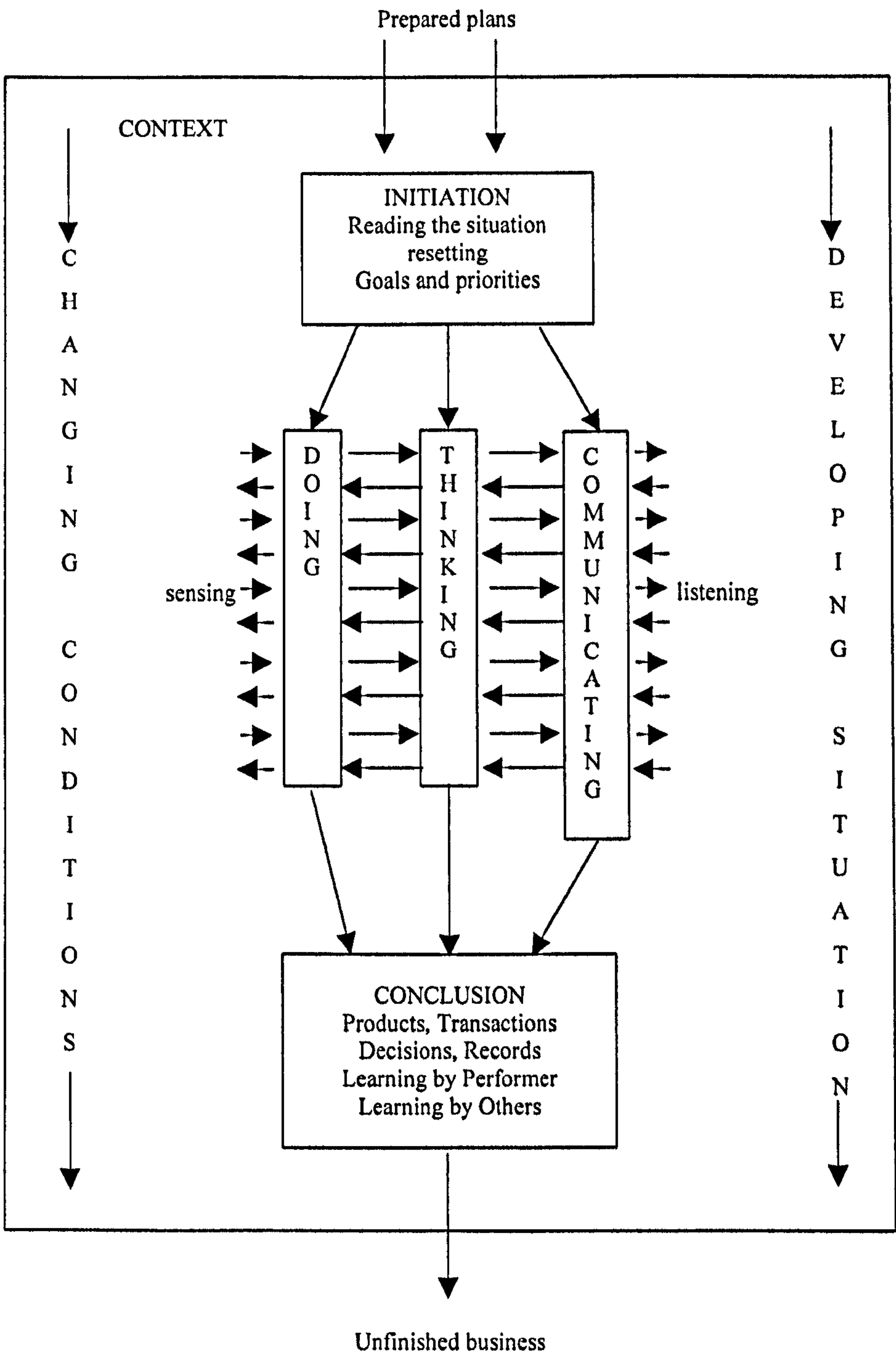


Figure 7: Activities during a performance period (from Eraut, 1994, p. 151)

The performance model is a dynamic model accommodating the flux of daily work. While plans may play a part in preparing for the work, they do not dominate its execution. Once the activities of the performance period start, the professional's action sequence is affected by the speed at which the issues arise (Table 2).

While carrying out their work under time pressure, the professional responds with routinised unreflective actions which arise from their training and their expertise. As time pressures lift, for example after work, they engage in deliberation. Eraut suggests that deliberative action is seldom encountered during performance periods because of the difficulty of competing demands in such situations. It is not called for except when the unexpected occurs and, when this does happen, the professional is typically pressed for time and may not even notice the problem. He suggests that deliberative acts such as planning, problem solving, analysing, evaluating and decision making, lie at the heart of professional work

Eraut notes that an architect's life will consist of projects which span over long periods of time, even many years. Over this time, the architect will engage in intuitive and analytical thinking, learning from their experiences on the project. This learning will be carried forward through a project as well into other projects as a knowledge base for their professional work. Expertise is acquired through extensive effort and practice (Chase & Ericsson, 1982; Chase & Simon, 1973; Hayes, 1985). Quist's mastery arises from his having designed for many years and, more importantly, deliberated on what he has done. Petra, the student, is not



deliberating at the time of the encounter with Quist. She is accumulating the information being conveyed and will probably deliberate on it after the class.

Eraut's model allows us to resolve the problems of contextual influences on a professional's actions with the mode of response. He gives us a tool with which to understand the changing nature of that response, from unreflective action, action monitored by reflection and action followed by deliberation. Based on this analysis, our understanding is that the solution for the problem at hand is informed by the particular context of the situation at hand, but it is one derived from an expert body of knowledge acquired through training and deliberation. As such, the work of the engineer in interpreting the tube structure is one of expert activity. As any expert would, the engineer works with the materials at hand (to ignore what data are present would be irresponsible) but this in itself is not sufficient to design the structure. This material at hand is supplemented by experience and informed by expertise. From this combination comes the design solution.

This framing of the process is supported by work in other fields. For example, the study by Hastie & Pennington (1991) of the jury deliberation process considered the process by which a juror changed their opinion. By examining video tapes of the two minute period before the change occurred, the authors discovered that those times were filled significantly with more discussions of law, legal procedures and definitions of verdicts than other periods within deliberation. The jurors were calling upon knowledge and developing their expertise on these points

of law. This is in contrast to a situated action which would find the jurors engaged in the deliberation of personal positions and subjective opinions.

The proposal to be empirically evaluated in this thesis is that architectural design is an activity that depends upon the knowledge and experience of the person participating. This knowledge is gained through learning, doing and deliberating. Decisions made by the architect are made by drawing upon this expertise and, most importantly, that the above claims also hold for architects working collaboratively. The context of the design process is influential in so far as it offers tools to assist in the design process but these are interpreted through the knowledge of the architect.

The explanation so far has not addressed the role of the drawings as highlighted by Gero. As the example above illustrates, the information we need to carry out design is sometimes located in the world around us, not only in internal representations in our minds. This is the position that Suchman takes when she states that "planned, purposeful actions are inevitably situated actions" (1987, p. viii). Traditional cognitive models account for these external objects by postulating complex internal representations (Suchman, 1987; Simon, 1996). An alternative view is to consider these external objects as components in a distributed representation of information which includes both internal and external forms (Zhang & Norman, 1994). Cognition can then be considered as a distributed task which draws upon the internal and external representations.

Designers working together, whether with computer-mediated tools or in face-to-face settings, sketch to communicate and explore ideas. These drawings have been shown to be essential tools in discovery of the design space (Goldschmidt, 1994; Goel, 1995; Suwa & Tversky, 1997). Beyond this, however, drawings serve as extended working memory, archives of ground covered and devices for communication during collaborative design (Zhang, 1997).

External representations in general, be they drawings, manuals, interfaces or information in other people's heads, affect our work in several ways. Zhang & Norman (1994, pp. 118-119) propose four roles. First, they act as memory aids. Secondly, they provide information that can be directly perceived and used without being interpreted and formulated explicitly. Third, they can constrain the range of possible cognitive actions, thereby anchoring cognitive behaviour. Fourth, they change the nature of the task even if the abstract structure of the task is the same as one without an external representation. From this view, Zhang and Norman state that external representations are intrinsic to distributed cognition for without them it could not exist.

Donald (1991) suggests that the external symbolic system, especially writing, is the most important representational system, responsible for much of the enormous cognitive capacity of the modern mind. It could be said then that drawing plays a similar role in enabling us to think graphically, just as writing helps us to think verbally. Goldschmidt (1994, p. 158) postulates that sketching is "a rational mode of reasoning characterised by systematic exchanges between conceptual and



figural arguments.". She refers to sketches as "interactive imagery" in which ideas are explored before they are understood, to "avail oneself of meaningful clues" (1994, p. 164) which can be used in subsequent design development. This is resonant too with Olson, (1996) who argues that the act of writing brings structural properties of speech into consciousness. Thus the invention of writing brought about a discovery of representable structures of speech. This suggests that the act of drawing is itself may be helping us to recognise permissible actions of design.

Zhang (1997) concludes that external representations are integral to the cognitive task of problem solving, being used as a cognitive tool and are not accessed directly in an adaptive manner as the situated action theory would require. Thus in Gero's example of the engineer discussed above, the data presented in the way of drawings are external representations which are informing the actions and decisions of the engineer, enabling the act of distributed cognition.

Collaborative design draws upon a group experience which is informed by the individual contributions of the participants in the design project. Problem solving and designing occurs in different individuals within the project, whether according to their role as specialists or within teams of similarly skilled individuals. The design effort occurs at different times, sometimes when the group or members of the group are together, at other times while they are working apart or in individual settings.

While the context of collaboration can be understood in Latour's terms of a network of knowledge and distributed memory as discussed in Section 2.5.1 above, the means of accessing this knowledge has not been addressed. By using the concept of distributed cognition, we can tie these networks to the task. Thus, the activity of collaborative design is distributed cognition (Hutchins, 1991). As Hutchins notes, such activities consist of two kinds of cognition, "the cognition that is the task and the cognition that governs the coordination of the elements of the task" (Hutchins, 1991, p. 284).

There are important implications from this work when organising collaborative design teams. As Hutchins notes:

...if groups can have cognitive properties that are different from those of the individuals in the group, then differences in the cognitive accomplishments of any two groups might depend entirely on differences in the social organization of distributed cognition and not at all on differences in the cognitive properties of individuals in the two groups. (Hutchins, 1991, p. 285)

This implies that the selection of participants (students in an educational setting or consultants in a professional setting) is only as important as the consideration given to setting up the way these participants are to work together. As the research into brainstorming illustrates, groups properly supported do have the ability to produce richer results (Gallupe, Bastianutti & Cooper, 1991). Jablin and Krone (1994), however, note that this success is affected by the organisation of groups as well as the extent to which the group is conversant with the available rules and technology.

We agree then that design, in particular collaborative design, does require the designer to draw upon information and representations outside their own minds. The role of these external representations is in either informing the designer with data or to represent data during a cognitive act. The shortcoming in the argument that design is a situated act is that it does not tell us how these external representations are used. Regarding design as a representational act which draws upon external representations which are then cognitively processed by expertise satisfies that requirement. Taking Clancey's (1997, pp. 1-2) definition of situatedness, that thoughts are not merely interactive but directly linked to perception, conception and physical action in a situation (Clancey, 1997, p. 23), we can conclude that design is not a situated act.

### **2.5.3 A cognitive model of architectural collaboration**

Having established that collaborative design can be seen as a cognitive task in which knowledge and expertise is brought to bear on the problem, we can now consider in greater detail a cognitive model of collaborative design.

As noted in 2.3.2 above, the cyclical nature of design in an individual designer has been demonstrated experimentally by Gero & McNeill (1998). This cyclical nature of the work was then extended to propose a loose coupled model of collaboration (Figure 4). Eraut's model (Figure 7) also suggests that the architect engages in a cyclical collection of tasks in the process of doing-thinking-communicating actions of a performance period. None of these models, however, illuminate the process of collaboration and the cognitive processes which occur



during collaboration. A model must be created to describe collaborative design processes. In this section, such a model is proposed. It is then tested in Chapter 5.

Rowe has noted a similar phenomenon in design teams (Rowe, 1987). He observes that design is inherently cyclical, characterised by movements between explorations of architectural form and more technical issues. The exploration of form is guided by organising principles brought to the process by the architects and by the constraints of the project. His view therefore also supports the observations of Purcell, et al. (1996) and Suwa & Tversky (1997).

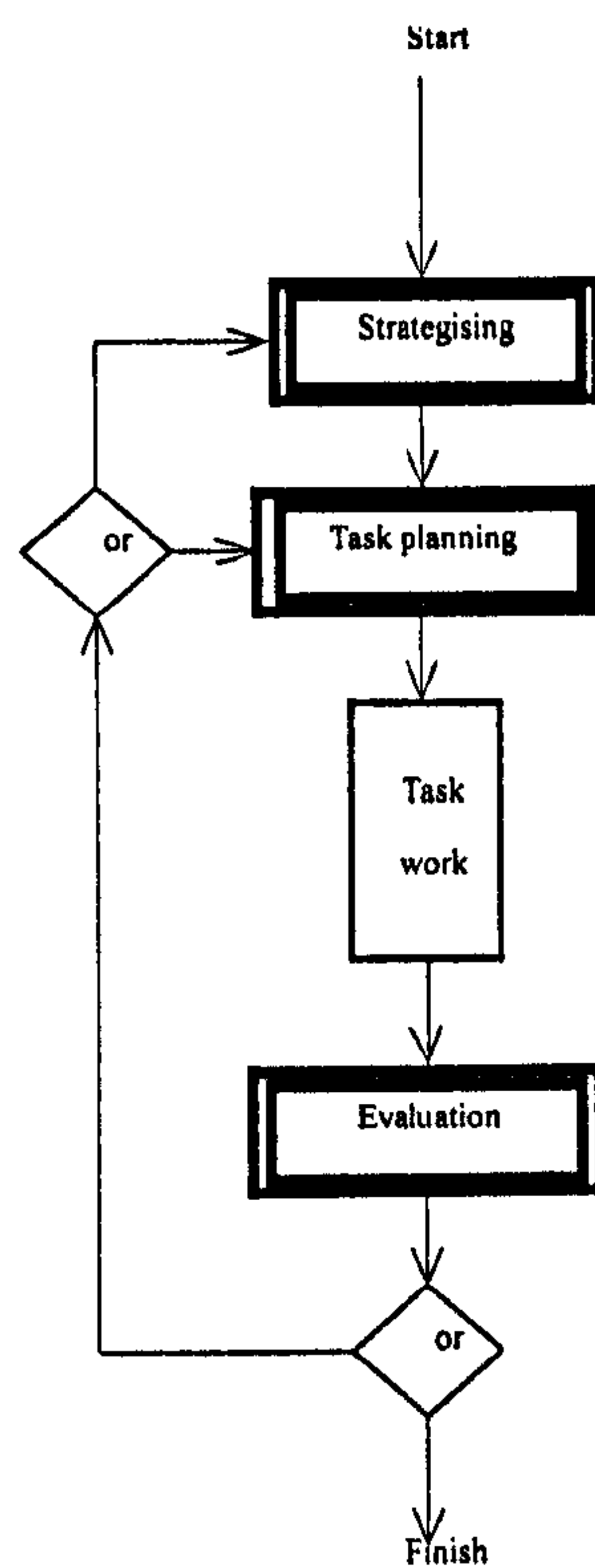
As Rowe points out, a considerable effort is generally required to get the initial concept to work rather than dropping it and starting fresh, thus we would expect initial negotiations, at least by experienced architects, to focus on establishing agreement on a guiding concept, that is, establishing complementary goals and shared belief systems. This is the process described by participants in the AIA research in to excellence as the process of "educating the client" (Franklin, 1989, p. 46). Following this, Rowe describes, "periods of unfettered speculation, followed by more sober and contemplative episodes during which the designer, 'takes stock of the situation.'" Rowe also notes that, "during moments of clear problem definition more straight forward procedures are used," followed by an evaluation of their success.

The process is not linear and smooth. Klahr (1998) has noted how, as a participant in collaborative problem solving, there are times when he wishes to remove

himself from the process in order to reflect, then rushes back to engage with his collaborator when an insight is reached.

We need then to construct a cognitive model of collaboration by which we can examine interactions between participants. Note that this model is not an attempt to state categorically that this is the way people work but more a rhetorical model by which to make explicit processes so that we can then forge tools to support collaboration.

To construct a model of collaboration, then, we start first with a model of individual design process. A simplified model of design can be derived from Simon's problem solving model (Simon, 1996) in which design can be described to start with a strategising step, proceed through problem exploration and end with an evaluation of the results of that step. These steps echo those found by Purcell, et al. (1996) where they identified goal management, planning and task analysis as parts of the design process. We could then postulate a model of individual design which consists of strategising, task planning, execution of a step and evaluation of the work accomplished in that step (Figure 8). The cycling can be very fast; in experiments by Gero & McNeill these cycles took in the region of 15 seconds or less.

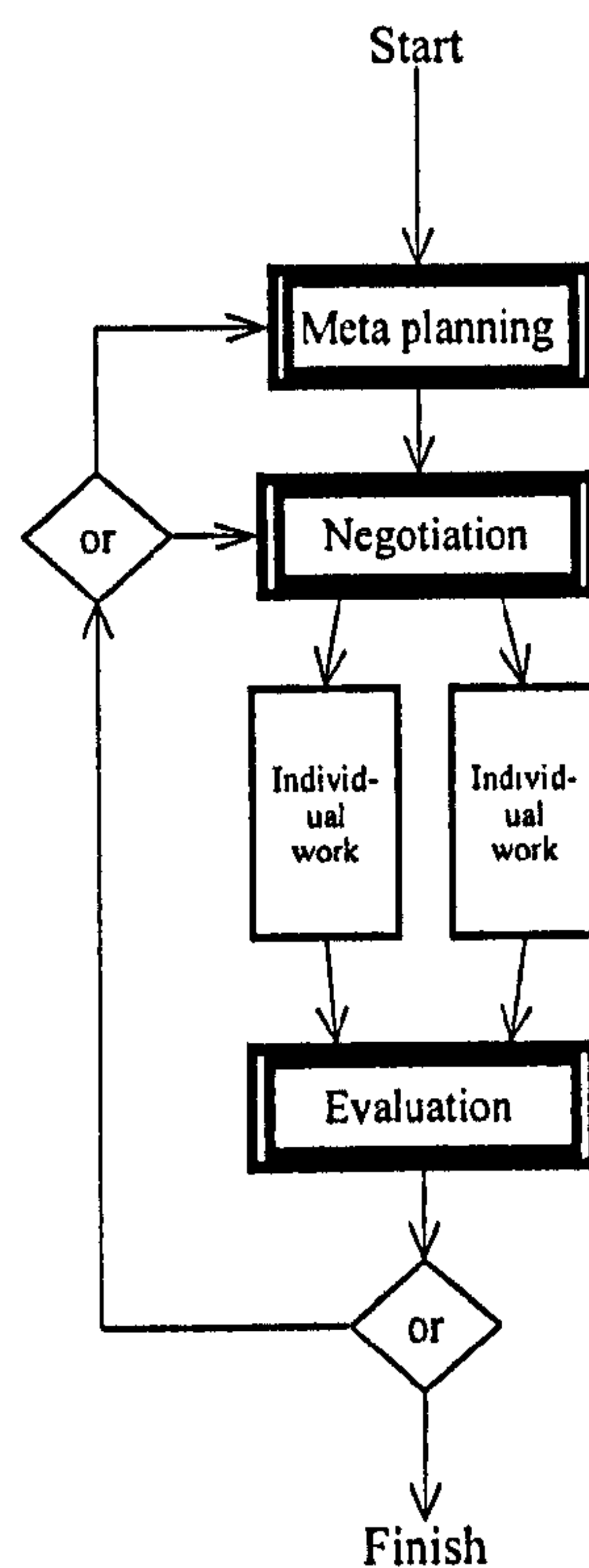


**Figure 8:** A cognitive model of individual design

In a collaborative project, we would expect initial contact to be one of strategising, marked by a negotiation or directions and responsibilities, followed by individual creative problem solving and interactive evaluations of the solutions.

Assuming that the act of collaboration does not fundamentally change the way we work (a view for which no evidence can be found), the model above allows us then to construct a cognitive model of collaboration (Figure 9).





**Figure 9:** A cognitive model of collaborative design

The first step involves a process of planning how to execute the task in a coordinated way. It is a “meta” planning process in the sense that it is about how to break down the problem into individually manageable units as well as about how and when the collaborators should come together to integrate their individual efforts. This part of the collaborative process does not really deal with the design problem itself, that is, with the real content of the task, but only with how to approach doing it collaboratively. This process is followed by another cooperative step – *negotiation* regarding specific aspects of the design problem. Following an initial negotiation (this process could just as well be referred to as interactive or joint decision-making), each expert participant separately engages in

well-learned routine problem-solving guided by the meta-plan that was agreed upon and constrained by the jointly-made, task-specific negotiated decisions.

Each collaborator then works on their own pieces. This individual working is essential, not only for routine tasks of task execution but also in the creative process where solitude is necessary for creative thought (Freyd, 1994; Klahr, 1998). This model is supported by the process of collaborative work proposed by Fruchter, et al. (1996) embodied in their software prototype called Interdisciplinary Communication Medium (ICM) to support communication in collaborative building design. In this model, they offer a central, shared graphic model which is connected to multiple symbolic models which provide automated reasoning about the design from multiple discipline contexts. The system supports artificial intelligence (AI) modules which support the communication between different disciplines by employing a paradigm for communication they call *propose-interpret-critique-explain*. This is based on the *propose-critique-modify* paradigm from Chandrasekaran (1990). The component which is missing from their model but present here in this cognitive model is that of meta-planning or framing of the problem.

Several studies have concluded that collaborative design is a social activity. The discussion in Section 2.5.1 above clarifies the statement and agrees with the conclusion. A test of the model then is the extent to which it permits social issues to be accommodated. Inspection of the model shows that the social aspects identified above, namely the development of social knowledge, the enactment of

social roles and the process of socialisation are not denied by the cognitive model. The processes of planning, negotiation and evaluation permit the steps necessary for carrying out these social roles.

The cognitive model here is also supported by findings in the categorisation of design collaboration identified by Maher, Cicognani & Simoff (1997) in their analysis of collaborative design experiments, namely:

- Mutual collaboration, in which the participants are “busy working with the other”
- Exclusive collaboration, in which the participants “work on separate parts of the problem, negotiating occasionally by asking advice from the other.”
- Dictator collaboration, where the participants decide who is “in charge” and that person leads the process.

Indeed, Maher, et al. note that the ‘exclusive collaboration’ model is the most effective and the one in which they observed most productive results. Mutual collaboration led to no result at the end of a very busy exchange between the participants, whereas dictator collaboration came to a conclusion as soon as the leader made up his mind. In the context of the earlier discussion about co-operative processes, we can see that the work is in fact co-operative in nature, and that collaboration is manifested as negotiation and evaluation.

When the participants have completed their agreed upon components, they interactively evaluate the outcome and are then either finished or they reiterate the steps. Additional meta-planning may or may not be required and the process may begin again following further task-specific negotiation. If this model is correct then the tools used to support collaborative work should focus on facilitating the



meta-planning, negotiation and evaluation components of the process. Otherwise, the tools should be no different from those used for individual work, except for requiring a means to share the results (this is of course a non-trivial problem in itself).

Experienced designers working collaboratively on a problem should behave like typical experts in any other area of expertise. They should have larger chunks of knowledge which they can apply quickly and in a fairly error free way. They should be able to work forward from the initial state of the problem, while novices tend to use strategies such as working backwards from the goal (Bedard & Chi, 1992). Experts should be able to reason by analogy from a large base of well cross-referenced knowledge about the field. They also plan better and monitor their progress more carefully. That the best architectural practitioners place great emphasis on the initiation of design exercises is documented by Coxe:

“The purpose of the (predesign) phase is to explore the program with the client to the point where there is common agreement on an idea and direction...to cement the architect-client relationship and to establish project direction” (Coxe, 1989, p. 93)

Cuff (1991) also discusses the need for this kind of activity early in architectural projects.

The sort of cognitive processing demonstrated by experts on well-learned tasks allows us to characterise the process of problem solving with a reasonable degree of accuracy. The central assumption of this model is that collaborative work by experts will look very much like individual expert work. There are additional

processes, those we have labelled as meta-planning, negotiation, and evaluation, but even these are interactive extensions of processes that individual expert problem solvers carry out anyway. In contrast, we would expect novice collaborators to be poor at setting up effective meta-plans, resulting in a rapid and repeated need to re-negotiate.

It is clear that, in addition to the problem-solving process, collaboration will also involve personality, emotion, and many other social/psychological factors. We suggest that these do not play an important role in shaping the measurable outcomes of the design process. It can be argued that the outcomes are primarily shaped by the skills and expertise of the participants – i.e. the knowledge component of the collaboration rather than the social or situational ones. As discussed in 2.5.1 above, socio-cultural variables, and non-knowledge-level individual differences will influence many aspects of collaboration in defining the social knowledge available, affecting the roles of the participants and the way they are enacted, their work models. These variables will not, however, have a significant impact on the measurable outcomes of the process. These variables, which are unrelated to the task-specific knowledge of each participant, may affect things like the degree to which the collaboration is enjoyed or disliked, but the real result of the collaboration, in this case, an architectural design, will be largely the consequence of the knowledge and experience of each collaborator.

This cognitive model of collaboration is that used as a basis of the experimental examination of collaboration in Chapter 5 below. Its implications for collaboration are further explored and discussed in the experimental framework.

## 2.6 Discussion

The previous sections have examined the views that design is social, situated or cognitive. This framework is necessary in order to define the context in which we are identifying tools to support distal collaborative design. The need for this clarification can be illustrated by examining Mitchell's assertion that:

“the most interesting new directions (for computer-aided design) are suggested by the growing convergence of computation and telecommunication. This allows us to treat designing not just as a technical process... but also as a social process.”  
(Mitchell, 1995a, p. 8)

The implication is of this statement is that design was a social process until users of computer-aided design systems were distracted into treating it as a merely technical process. The unspoken assumption appears to be that putting the participants into an environment with maximal communication channels will enable the social process and therefore result in better design collaboration. Most readers will conclude that increased communication between design participants will necessarily lead to better social interaction which itself begets better design. From this position, we conclude that CSCD tools must permit the optimal communication and the best social interaction.



The likely danger here is that we will repeat mistakes from our brief history of computing in design which may lead us into less than useful activities. As with several commercially available computer-aided design (CAD) systems used in architectural design, CSCD implementations all too often are poor imitations of manual systems. These CAD systems are not good implementations of computing tools in large part *because* they have mimicked manual methods.

For example, few in the field will argue with the statement that the best approach for data storage in a computer-aided drafting system is the storage of data in layers. Layers derive from manual overlay drafting technology (Stitt, 1984) which was regarded as an advanced (manual) production concept at the time many software engineers were specifying CAD software designs. Some early implementations of CAD systems (such as RUCAPS, GDS, Computervision) avoided such data organisation, the software engineers recognising that object-based structures are more flexible, permitting greater control of data editing and display. Layer-based systems, however, are easier to implement in software; the concept is more familiar to the user and hence easier to explain; the system is easier to use initially but more limiting for an experienced and thoughtful user; all these leading in the end to a lesser quality in resultant drawings and significant problems in output control (see Richens, 1990, pp. 31-40 for a detailed analysis of such features and constraints).

Similarly, Flemming, et al. 1997) observe that transposing the T-square and overlay drafting metaphors from the physical drafting desktop to the computer

desktop has not proved beneficial. They note how training manuals emphasise the metaphors in order to make new users feel comfortable with the transition. In their research into training for efficient CAD usage, drafting in CAD can be better accomplished not by enacting the manual metaphors but reconstructing the task to suit the characteristics of a computer system. In these two examples, we see the design for architectural software faithfully but inappropriately following manual methods.

So, too, is there a danger of assuming that the best design interactions are done face-to-face and to conclude therefore that all collaborative design communications environments must mimic face-to-face. In the sections above, we have seen that design requires a group of participants to come together to share a task and contribute their expertise in solving the design problem. To this extent, the social aspects of design must be considered. Whether the activity of design is formally a *collaborative* activity or an activity carried out by nominal groups (a collection of individuals working on a common problem) can be argued separately. To go beyond this and say that design is determined by the social milieu within which it is executed requires us to agree that design is situated.

Traditionally, there are many different patterns of work (Lawson, 1994). Designers can be colocated, working physically together to find solutions, or the design process is divided into discrete steps which can be executed serially. At other times, we send designs serially (asynchronously) one to the other. The fax machine has been the technology of choice in recent years, supporting this mode

of design. In the former instance, designers work *synchronously*, face-to-face; in the latter, the work is carried out *asynchronously*, each expert contributing their expertise separately. A third mode can be considered too, the semi-synchronous mode (Hollan & Stornetta, 1993). In this mode, teams will divide up and tackle the same design problem in smaller groups, looking for a variety of solutions to a problem. After a stipulated time, teams gather again and pin up their sketches for comparative reviews.

The frequent conclusion, then, has been that when computers are applied to collaborative practice to overcome the problems of distance, we should apply video and audio technologies to create transmission as comprehensive as possible. A common assumption in establishing computer-supported collaborative design arrangements is that the closer we approximate physical space, the better the design experience and the better the design solutions. It may not be the case, however, that the best solution is mimic the conditions of physical proximity, whatever they are. Indeed, by replicating physical proximity, we may be falling into the same trap that early CAD users did of poorly mimicking manual methods and failing to discover benefits inherent to the new technologies.

The unstated assumption is that computer-supported design environments are not adequate until they replicate in full the sensation of being physically present in the same space as the other participants (you are not there until you are really there). It is assumed that the real social process of design must include all the signals



used to establish and facilitate face-to-face communication, including gestures, body language and all outputs of drawing (e.g. Tang, 1991).

The work of Xerox PARC in the use of high bandwidth communications in design settings (for example, Bly, Harrison & Irwin, 1993) is a typical example of research grounded in a situated action framework. In this framing of the problem, high bandwidth communication is necessary to simulate the face-to-face context of design, as it is only in such a context that rich design solutions can be obtained. A major part of the work to date has assumed the position that design is a social activity and design is, therefore, a situated activity. From this assumption, it then flows that technology to support distal collaboration must support social interaction. Implementation of CSCD in educational settings has followed similar assumptions (Mitchell, 1995a; Sheldon, et al., 1995). Thus, when wiring up a design studio for teaching to support situated action, the need is for a high bandwidth and extensive use of video cameras to achieve a shared space between both ends of the connections. It must be stated, however, that there is no evidence to suggest that this improved communication leads to better design outcomes.

If, however, the assumption is that situated action is not dominant in its contribution to the outcomes, that cognitive processes dominate the design process, then the connective technologies can operate at a lower bandwidth with less emphasis on tools to achieve a common space. If knowledge and expertise are the govern the quality of the outcomes more than the context of action, we can develop tools and procedures to facilitate the communication and collaboration. If

the social dimensions of design are those identified earlier, then we can accommodate the need for social interaction through means other than high bandwidth.

After reviewing the arguments, we can conclude that design is a cognitive and expert activity. Social aspects of design which do play a role are those encapsulated in the professional context of the activity. Tools to support CSCD should therefore focus more on the cognitive processes rather than the situated. They can support the expert activities of an architect rather than simulating the place within which the activity takes place.

We can also agree with Mitchell, as quoted at the beginning of Section 2.6, the most interesting new directions *are* suggested by the convergence of computation and telecommunication but the interest stems from opportunities to rethink and reconfigure our professional work as architects. The opportunities lie in reconstructing the way projects are carried out, not in extending what we already have, not replicating existing collaborations in digital media. The pursuit of "being there" obscures the goal, and wastes our efforts.

## 2.7 Summary

This chapter has reviewed the background of architectural design, design theories and process models for design collaboration. An understanding of this background is essential if we are to specify tools for CSCD.

Architectural design of anything but the most trite or restricted problem is a collaborative activity. The nature of the collaboration is typically loose coupled — that is, the participants in a project must work together to provide solutions to different aspects of the problem. In this way, they are co-operating on the problem solving rather than working hand in hand.

Most of the time when people think they are working collaboratively they are only co-operating and, even more important, compromising. And most of the time that is exactly what they should do. Collaboration is time consuming and requires relationship-building and is only suited to very particular problems that require such close coupling of the design process and its participants. It would be inappropriate to collaborate to accomplish most design tasks, in the strictest meaning of the word. In short, working together, even effectively, is not necessarily collaboration, a conclusion reached also by Sudweeks & Allbritton (1996) in their review of scientists using bulleting boards for communication. Nor should it be. The term *collaboration* is a deeper, more personal synergistic process and the term should be used selectively.

Perhaps we should refer to our field as “co-operative design”, recognising that the design process itself is one of negotiation, agreement, compromise, satisficing in order to achieve success (Cross & Cross, 1995, pp. 166-169). We might even talk about “compromised design” at the risk it might imply the wrong notion.



Whether we are co-operating or collaborating, we can be designing, but our expectations for the design environment changes if we think we are doing one rather than the other. A loose coupled design process requires a very much different set of tools and conditions to be successful than a close coupled one. Collaboration requires more than effort, machinery and systems to occur. Many working in this field appear to have their vision clouded by the issues of collaboration itself, failing to recognise the broader and far more important issues of systems for co-operative work.

Architectural design is a social activity only in that it takes place in a context of society and people. Designing a building draws upon a network of knowledge, in Latour's sense (Latour, 1987). This network forms a web of distributed information that is used by the participants, using the concepts of Zhang and Norman (1994). The network of knowledge and rights defines the profession. Professional roles establish the social context of the work (Harré, 1993). The actions of design, however, are not conditioned and programmed by the social being of man. The social context of design is the larger society of the profession itself.

Stemming from this, we conclude that architectural design is not situated. It is an activity which takes into account, to varying degrees, the context and the actions of the design process, but it is not embedded and only understood through the situation in which it has arisen.

It is apparent that the kind of collaboration we are talking about when referring to collaborative architectural design is distinct in important ways from that to which the term refers in other settings. For example, McGrath & Hollingshead (1994) describe the term in a more intimate or encompassing sense.

Collaborative work also entails emotional and motivational aspects of communication: Group members are also transmitting, receiving, and storing the affect and influence aspects of those same messages. (McGrath & Hollingshead, 1994, p. 7)

While it is true that all communication is subject to the particularities of the moment and the setting, it is also true that professional communication is subject to more constraints in interpretation. Furthermore, as we have all learned with the telephone, there are many ways of transmitting emotional and motivational messages beyond those appropriate for face-to-face communication.

Professional communication is project focussed. That is, the participants in a collaborative activity are goal-oriented in their efforts. As Dhar & Olson (1989, p. 34) note, such goal-focussed work has two facets, communication and problem solving (which includes planning, monitoring, negotiating and decision making). Broadening the definition of collaborative work to non goal-focussed work expands the role of the tools considerably and loses focus in their purpose.

These statements are true of the typical project, but with one proviso. There is no typical project, each has its own exigencies. In any given design problem, it is possible to find exceptions to the statements here. To prove the point, however, that design is not essentially situated, look at a body of work by one 'good'

designer. The consistency of the work from project to project will demonstrate that the design solutions are formulated under conditions which are larger than any one project, any one situation. This guiding principle can be called the architect's "design philosophy" and, often, the architect can expound this philosophy with clarity and in detail.

## 2.8 Conclusion

Collaboration is an essential element of architectural design. If CSCD is to be effective, it must support excellence in design, not only rote or impoverished design. Excellence is realised when the participants are able to interact, make their concerns heard and deliver their contributions effectively. Their contributions may be discrete knowledge-related input or process contributions. Design, as a loose coupled process, can be considered as either product or process related, each formulation being necessary at different points in a project. Such a process can be supported by a variety of tools, as best fit the users or tasks.

Schön's action theory and its formulation of design as a conversation underpins almost all VDS experiences to date. From the analysis in Chapter 2, I have explored the implications of action theory for collaborative design and found it wanting. As Eraut has noted, Schön's formulation fails to account for the various speeds at which professionals respond to different situations nor does it explain how knowledge is accumulated. Eraut's framework is therefore more helpful when



formulating CSCD environments, helping us to see that it is not only action that is important but also deliberation and assimilation of knowledge.

CSCD environments that emphasise the action environment focus on the situated formulation of design. This emphasis has been at the expense of the cognitive framing of design interaction. Architect's collaborating work on knowledge-rich problems and explore responses by calling upon their accumulated expertise. The situated framing is therefore inadequate, although it usefully reminds us of the relevance of data gathered from problem description and analysis. A cognitive framing of design supports a better understanding of collaboration and therefore offers a more fruitful base on which to investigate CSCD. This framing also permits us to accommodate the understanding that design is a social process in that a professional process requires the participants to act within their professional and client contexts, drawing data from the context. From these perspectives, we can conclude that CSCD tools need to support the expert act and that collaboration does not need to simulate "being there".

The next chapter will examine research in CSCW and work to date in CSCD. In this examination we will identify a CSCW framework by which to identify tools for CSCD. On the basis of the work in this chapter and the next, the thesis then proceeds in Chapter 4 to identify the technologies which can be used to support CSCD.

### **3 Computer-Supported Collaborative Design**

Research in the area of Computer Supported Collaborative Design (CSCD) builds upon the foundations laid by earlier research in computer-supported co-operative (or collaborative) work (CSCW). This chapter reviews the history of CSCW and its extension into CSCD. A review of documented experiences in CSCD is summarised and represented in the framework of CSCW research. From this opportunities for further CSCD research are identified.

### 3.1 Communication for Collaboration

Collaboration through telecommunication tools is not a new idea. Ever since we have been able to imagine such technologies, they have been proposed to serve design communication. As noted in Chapter 1, Wiener (1954), used the example of the architect to illustrate the possible value of fax technology early in its evolution. Mitchell (1977) documented the many early implementations of computer systems which focused on the problems of storing the extensive data of an architectural project so that the many participants could access the information and co-ordinate their efforts.

As technology moved on and permitted broader band-width network communications and hardware developments permitted exploration of more sophisticated user interfaces, we began to see the explorations of the needs and constraints of shared drawing systems (Bly & Minneman, 1990; Tang & Minneman, 1990). Since 1993 and the growth of Internet access, we have seen a greatly increased interest in collaborative design applications of computer technology. Collaborative drawing environments have been investigated in several schools of architecture setting up studio projects based on digital collaborative environments (Wojtowicz, Davidson & Mitchell, 1992; Kalay & Séquin, 1995). Most of this research has been in tools and environments which attempt to replicate the face-to-face design encounters within an office or teaching studio. An extensive review of this work is presented below on pages 119 to 140 of this thesis.



Professional applications of collaboration started with several practices exploring the use of dial up and leased line connections in the early 1980s (Kemper, 1985). With the difficulties encountered, tightly linked collaboration (such as synchronous designing) was abandoned and practices moved back to asynchronous computing, such as sharing data by disks (Novitski, 1996). Computer networked communication between professionals started to appear in later years as reliable networks were established and professional work methods adapted to accommodate the technology (Grønbaek, Kyng & Mogensen, 1993).

That computer-aided design systems have failed to support collaborative computing is clear. Experience in practice has been that the systems are viewed as 'black boxes' into which work is poured but which is invisible to all but the immediate user (typically the 'operator'). As Franklin notes,

"Architecture is a team effort; when CAD is used, there are hand-offs. Hand-offs in any form are problematic and expensive...I find that the firms using CAD with the happiest results are the one-person automated firms." (Franklin, 1993, p. 60)

Yet in some respects it is indeed 'black boxes' (Latour, 1987) which we want of computers, just as the most buildings are 'black boxes' to most occupants, a "machine for living", employed to achieve end results. How many people understand the piping and wiring which supports their existence? In this way, we do want our computer-aided design systems to be black boxes. We want them to reveal the data, not the workings of the systems. But to achieve this black box opacity, the designers must have a very clear understanding of what they are trying to attain in terms of the user's interaction and experience with the box.

There is already a considerable body of research work related to the role and application of computers to communication and collaboration, from which have arisen a variety of tools to facilitate work done in groups. Several surveys have been made of research directions in attempts to summarise and draw conclusions from the multitude of approaches and results, (Siegel, Dubrovsky, Kiesler & McGuire, 1986; Galegher & Kraut, 1990; Greenberg, 1991; Easterbrook, 1993; Holtham, 1994; McGrath & Hollingshead, 1994; Nunamaker, et al., 1995; Eason & Olphert, 1996; Finn, 1997). Holtham (1994) traces this history from the 1960s through to the 1990s, noting that the initial work in the field addressed the basic technical issues of computer communication. As the field evolved, sociologists became interested in the human aspects of computer-based communication and research began to include looking at the nature of the communication enabled. In later years as the technology has stabilised, the focus has moved to commercial implementation and diversified applications of the tools.

Siegel, et al. (1986, p. 157) categorise research into these tools into four areas: technology assessment studies; organisational studies; technical capabilities studies; and social psychological studies. Little of this research has focused on the work of designers, with no commercial systems available specifically for the design professions. Research has tended instead to look at typical office work, with particular attention to group work in formal and informal but coherent groups. This research provides a rich and useful heritage for investigations of design collaboration, but the findings have to be interpreted with the recognition

that design work differs from typical office work in one substantial aspect – the use of graphics is central to design communication and this places a significant and different burden on the computer-supported communication when compared to textual interactions.

### 3.2 A framework for CSCW

As computers have come to be seen as useful in supporting the process of group work, a wide range of tools have been evolved to support this work. Equally diverse are the terms used to refer to them. Johansen (1989) notes fifteen different terms used to describe all or part of the range, reflecting the incremental development of tools to suit particular aspects of collaboration to be supported.

One term commonly used to describe all tools to support work by groups is "groupware". As Greenberg defines it:

Groupware is software that supports and augments group work. It is a technically-oriented label meant to differentiate "group-oriented" products, explicitly designed to assist groups of people working together, from "single-user" products that help people pursue only their isolated tasks. (Greenberg, 1991, p. 1)

Others, such as Galegher and Kraut, define the role of these systems which "help people engaged in collaborative intellectual work communicate and structure their work" (Galegher & Kraut, 1990, p. 3).

A more useful schema is offered by McGrath and Hollingshead (1994, p. 8) when they simplify the field by identifying four categories of technologies that modify group processes (each with their own acronyms), namely:



- facilitating the groups' internal communication system (GCSS)
- the group's communication with information bases (GISS)
- facilitating the groups' external communication systems. (GXSS)
- structuring the group's performance processes (GPSS)

In subsequent discussion, McGrath and Hollingshead draw little distinction between the internal and external communications (GCSS and GXSS), noting that for both the technologies of communication and fields of research are similar.

For both internal and external communication, technologies to support collaboration at a distance are summarised in six groups (Table 3). These technologies are contrasted to the experience of synchronous collocated face-to-face meetings. Note that distal asynchronous tools support simultaneous but asynchronous exchanges as found in electronic meeting systems (EMS) (Nunamaker, et al., 1995) electronic brainstorming (EBS) (Gallupe, et al., 1991), electronic bulletin boards (EBB) can be classified as synchronous tools in that they can be applied in real time by groups to communicate.

Table 3. Types of Communication Tools for Collaboration  
(after McGrath & Hollingshead)

	Distal, Synchronous	Distal, Asynchronous
Video / Audio	Interactive video	Non-interactive video, including e-mail video clips
Audio	Telephone conferences, including Internet phone	Voice messaging, including voice attachments to e-mail
Text / Graphics	Interactive computer conferences	Non-interactive computer conferences including e-mail

3.3 Lessons learned

It is not necessary here to review the various directions and conclusions of the great wealth of research which exists but it is useful to identify key learnings which can illuminate the operation and success of a virtual design studio. Benefits from CSCW are reported in many studies. These benefits can be summarised under three headings:

- process structure benefits
- greater participation
- better results

The following sections provide a brief summary of the findings in CSCW research in each of these three headings. Many studies report the benefit of overcoming distance or time but this is not a result but the mechanism by which the benefit is realised. Therefore they are not to be included as a benefit.

### 3.3.1 Process structure benefits

A number of CSCW support tools are specifically designed to structure the exchanges between participants. Research by Nunamaker and his colleagues, for example, have found that the use of an electronic meeting systems (EMS) will introduce a structured process which can improve decision making (Nunamaker, et al., 1995). The computer system through which the participants are interacting may demand a particular sequence or method of interaction, this method having been determined to be beneficial through earlier research or through participants of the session agreeing on a particular way of collaborating.

A review of nineteen sets of reported empirical results by Kraemer and Pinsonneault finds overall support for this contention. They note that decision support systems (GDSS) lead to group members having greater confidence in the results and hence greater satisfaction with the decision. In particular, their review of the studies leads to the conclusion that GDSS systems

- increase the depth of analysis;
- increase the task-oriented communication and the clarification efforts;
- increase the degree of participation and decrease the domination by a few members;
- increase consensus among members of the group.

They note four caveats:



- there is a lack of control for the effect of greater structure resulting from technology;
- they do not monitor the effect of the facilitator if present;
- the studies tend to favour participants who are inclined to use computers;
- the studies focus on early stages of group development (Kraemer & Pinsonneault, 1990, pp. 393-4).

This finding, however, is not limited to the realm of sophisticated CSCW tools. Having a process to follow helps a meeting be more productive (Watson, DeSanctis & Poole, 1988). Thus we can say that the benefit of a CSCW is in part the process and in part the support given to the communicative aspect.

The nature of the process being undertaken will influence the degree to which computer tools are able to be of help. The more difficult the process, the more likely that process structuring tools will be of benefit (Gallupe & DeSanctis, 1988). In their studies, a group decision support system (GDSS) was found to increase the number of alternatives considered and to improve decisions arising in problem-finding tasks. Most notably, they observed that the more difficult the task, the greater the improvement in applying a GDSS to the process.

Not all studies support these findings. Jarvenpaa, Rao & Huber (1988) report that groups working on unstructured problems obtained fewer benefits from applying electronic brainstorming technology than expected. In particular, they note that

the use of these brainstorming tools had to be supplemented by alternative channels of communication but this then placed a heavier burden of management of the technology by the user, which itself could then be counter productive.

### 3.3.2 Greater participation

The imposition of computers into communication between problem-solving participants permits more equal contribution from participants (Kiesler & Sproull, 1992). The participants of computer-mediated collaborations are observed to have reduced inhibitions about participating. Likewise, group dynamics are changed, permitting those who are suppressed in face-to-face meetings to hold their own ground in a computer-based group exchange. Similar to the results found in GDSS, Kraemer and Pinsonneault (1990) found that results of the GCSS studies demonstrated (a) increased depth of analysis; (b) increased participation and decreased domination by a minority; (c) decreased co-operation (although the detailed discussion on p.397 indicates the decrease only if GCSS is applied in early stages of group development); (d) increased time to reach decisions.

These benefits obtain when computer-mediated collaboration is compared to face-to-face meetings, the latter being burdened with many problems which affect their effectiveness. Typical of the research into communication we find the researcher looking into aspects such as:

"self-monitoring, extraversion-introversion, dominance-submissiveness, Machiavelianism, communication apprehensiveness, cognitive stress and anxiety, and field dependence-independence on communicative behaviors. Next, we review how communication is affected by one's gender, age, socio-economic status, status, power, race/culture, and physical disabilities.... We overview how

dialect/accent/language, speech rate, pausing, vocal intensity, pitch, vocal attractiveness, talk duration, self-disclosure, language intensity, and some other variables allow communicators to infer the social and psychological characteristics of others." (Giles & Street, 1994, p. 103)

An element of the success of these computer-mediated process tools is that they permit a level of communication which resolves many of the problems of face-to-face communication. Many researcher have found that computer-based anonymous communication reduces the barriers to communication (for example, Gallupe, et al., 1991 in brainstorming) by removing many of the complexities of face-to-face communication.

Kiesler and Sproull (1992) note that two orders of effects can be observed when tracing the implementation of communication technologies. While the first order effects of greater capabilities are easily noted when observing the impact of technology in communication, the authors think that it is the second order (and normally unexpected) effects which have profound impact on the success of the technology. These second order effects are not directly caused by the technology but constructed by the users over time. Thus the success of participation in face-to-face meetings is also subject to constraints from physical and social order. Electronic meetings can allow the social order to be reconstructed, opening opportunities for greater participation.

In other circumstances, it can simply be that electronic meetings are more appropriate than face-to-face sessions when the face-to-face meetings risk being dominated by loud talkers or "people who have less knowledge than they have prestige" (Kiesler & Sproull, 1992, p. 120).



This finding is supported by those of Dennis et al. who report that decision meetings using GDSS systems which do not tag the author (they call them 'anonymous GDSS') generated significantly more comments in all, as well as many more critical comments, than meetings supported by GDSS which tagged the author (Dennis, George, Jessup, Nunamaker & Vogel, 1988). Similarly, participants in an electronically supported task force engage in a more participative process than they do in a face-to-face situation (Bikson & Eveland, 1990, p. 267). Kraemer and Pinsonneault observe that this effect may only hold in the early stages of group development and not later when patterns of participation have been established (Kraemer & Pinsonneault, 1990).

### **3.3.3 Better results**

Computer-mediated exchanges often lead to better results. As reported by Kraemer and Pinsonneault, the efforts of participants using computer-mediated communication tools are more focused on the task analysis, leading to increased depth of analysis and decision quality. (Kraemer & Pinsonneault, 1990).

These positive findings are echoed in Jarvenpaa, et al. (1988) where positive effects on the thoroughness of information exchange and quality of team performance were found in the meetings in which electronic blackboard technology was available. Likewise, Gallupe, et al. report that electronic brainstorming systems supported the generation of many more ideas than face-to-face brainstorming sessions (Gallupe, et al., 1991).

### **3.3.4 Summary**

The strongest benefits to be found in CSCW so far are those of increased communication. Communication is improved not only by removing factors of time and distance but also by removing or reducing social barriers to communication. While there are problems in communicating with CSCW systems, users appear to adapt and accommodate the technology successfully. Other benefits of better process and better results are less widely supported but some researchers demonstrate their possibility.

The technologies used have been classified into a framework. This framework will be used to review work to date in CSCD to reveal the dimensions and extent of the research.

## **3.4 Experiences in collaborative architectural design**

A survey of papers on distal collaborative designs studios is carried out below to provide a perspective on the work which has been done in the field of CSCD to date. We will see that there is a lack of formal research in the application of computer-mediated communication in design processes. Most of the work done to date in the field of design has either focused on a transactional approach to design or anecdotal descriptions of experiences. The former suffers from examining the activities of drawing with no distinction between the actions which lead to the result and the result itself, while the latter suffers by not identifying and

questioning the assumptions upon which the design activity is based. This survey illustrates the contention in this thesis that the majority of CSCD implementations are based on an uncritical adoption of design process models and technology at hand. The results of the survey also identify areas available for future research.

Two types of material are presented below. In the first section are papers which have been presented at eCAADe (European Computer Aided Architectural Design), CAADRIA (The Association of Computer Aided Architectural Design and Research in Asia) and ACADIA (Association for Computer Aided Design in Architecture) conferences in the years 1994–1997. The second set of reports are briefer descriptions which have appeared in professional journals in the period 1993–1997.

Using the classification system established by McGrath and Hollingshead explained above, the efforts to date can be categorised and the emphasis revealed. This is not an exhaustive categorising of work to date, but examples are given to illustrate approaches. We will note that most efforts to apply computers to design collaboration have been in the communication realms of GCSS and GXSS, perhaps drawn to this by the same attractions to “being there” which Hollan & Stornetta (1993) suggest has driven much telecommunications efforts in the past 100 years and which reflect the assumption that design is a situated act.



### 3.4.1 eCAADe

**Bradford, Cheng & Kvan (1994)** describe the 1993 VDS set in Shanghai in which the Universities of Hong Kong, Barcelona, British Columbia, MIT, Cornell and Washington participated. Participants worked on a project located at a mutually remote site (Shanghai). The collaboration occurred using ftp and e-mail and concluded in a Picturatel-based videoconference presentation at which only MIT, Barcelona, UBC and Hong Kong participated. The videoconference images of participants was supplemented workstations connected to the internet on which images were loaded when prompted by those presenting.

**Grootel (1994)** describes a Gopher-based exchange of information at the University of Eindhoven Faculty of Architecture. As such, it is not really a VDS but an experiment in exchanging information in preparation for a VDS between Eindhoven and the University of Texas A&M which was subsequently held in 1994/5.

**Cabellos, et al. (1994)** describe the same VDS set in Shanghai as described in Bradford et al. The paper describes the Barcelona participation in some detail. They note that four technologies were used for communication, each with its own purposes and characteristics:

"e-mail: fast and easy to use...

ftp: less synchronous and predictable than e-mail but very effective

Collage, Vat and CUSeeMe: real-time audio-visual interaction over the Internet. Requires a coincidence in time between participants in a session..., adequate hardware and software, and patience, but the feeling of "live" connection, the interaction between the participants, and the simultaneous sketching on a whiteboard comes closest to a traditional working session

Videoconferencing: ...Most sophisticated and expensive technological option...  
 Recommendable for large numbers of participants and "rehearsed"  
 performances." (1994, p. 181)

**Martens, Voigt, Schmidinger & Linzer (1995)** describe an urban planning application. This implementation focuses on video conferencing immediately as the communication medium between participants, with a secondary application of VRML (virtual reality markup language) models. The substantial work described here is small, the major part of the paper being hypothetical in nature.

**Dobson, Dokonal & Kosco (1995)** describe a collaborative design studio between the Universities of Luton (England), Graz (Austria) and Bratislava (Slovakia). Participation in the studio was limited — only one student each in Luton and Graz joining six in Bratislava working on a project set in Luton. All communication was via e-mail and ftp, with e-mail considered the most valuable. Videoconferencing was not used.

**Grant (1997)** describes a collaborative project between the University of Strathclyde and the Glasgow School of Art to explore the potential of videoconferencing over broad bandwidth communications networks offered by the Glasgow Municipal Area Network. The collaboration shares lectures, design reviews, seminars and tutorials. Technology is extensive — three cameras are used in the design reviews, with operators supplied by Scottish Television. The paper describes the importance of good camera angles and production direction

**Lee, et al. (1997)** describe a collaborative design studio between Osaka University in Japan and Kyung Hee University in Korea. Data is shared in dxf

(drawing exchange format, established by Autodesk as the exchange format for drawing files) and VRML format. Participants communicated using a bulletin board for posting messages. After completion of the designs, DXF or VRML formatted 3D model data produced by various modellers were converted to RWX (Renderware exchange format). The RWX formatted data was stored in the project server which could be viewed by each participant. Objects could be moved and transformed in virtual space. Participants in the reviews were represented by avatars which could be chosen to express emotions.

**Martens & Dokonal (1997)** describe the third project in the series which started in 1995 between Luton, Bratislava and Graz and in this iteration includes the Technical University of Vienna. The primary interaction described is between Graz and Vienna (Luton and Bratislava did not participate) which tried to coordinate teaching schedules of supplementary courses to support the design studio. In addition to computer-based interaction, a two-day seminar was held for participants at Graz, so all participants met face-to-face. Other communication occurred using a bulletin board and VRML models. Design reviews were done asynchronously — students prepared homepages to describe their designs and comments posted to a bulletin board.

**Emprin, Giroto, Gotta, Livi & Priore (1997)** use asynchronous communication "during analysis phase", videoconferencing "for important moments, to verify a stage of the design or take a decision", and employs avatars in VRML models to



represent participants who are exploring a VRML model synchronously. No reasons are given for choosing the particular technology for specific tasks.

### 3.4.2 CAADRIA

Kusama, Fukuda, Park, & Sasada (1996) describe the use of a custom system for use by a group, collocated or not, to participate in a design project. The tool is composed of a set of "*locations*" (conceptually the same as rooms in a MOO) which provide a series of tools needed to support design collaboration. These locations are: a *coffee shop* which has a sketch board (a simple paint program) and media album (containing precedents); a *model shop* with a parts box and tools to assemble the parts into 2.5D models; a *design studio* to prepare presentations in VRML or QTVR (Quicktime Virtual Reality) and review the designs made; and a *presentation shop* in which a video room permits viewing of presentations and a drafting room permits preparation of 2D graphics. Participants can view work done by others but does not have any means to communicate with other participants.

Comair, Kaga & Sasada (1996) describe the application of web-based communication with a local government client. Schedule and design data generated by the designers (Sasada Lab) were posted on the web to which the client could gain access. Security was achieved by dividing information into public and private — public information was accessible by anyone with web access while private information was available only through a login procedure. E-

mail was used to send comments and communications to the participants, including images, movies, sounds and other file formats.

**Woo, Kim, Lee & Sasada (1997)** describes the lessons learned in using systems to support collaborative design projects run by the Sasada Lab, including projects between designers only, designers and clients and designers and the public. From these experiences, the Sasada Lab has developed a multi-user workspace tool for CSCD. The workspace consists of a private workspace (for the local user) and a public workspace for the collaborative activities. Data generated in the design exercise are converted to DXF, QTVR and VRML formats for sharing. In the design review process, participants can use a digital representation of their physical self, an avatar, to populate a VRML review model and interact with other participants. The system described here is that used in Lee, et al., 1997. No critical evaluation is given of the effectiveness of the system.

Although not conducted in laboratory conditions nor reported with rigour, **Morozumi, et al. (1997)** is a useful paper which describes the experiences of a five week VDS held between three universities, two in Japan (Kumamoto and Kyoto Institute of Technology) and one in the USA (Massachusetts Institute of Technology). Three students at each institution took part in a competition, forming three teams with one participant from each institution. The design project site was in Kumamoto, with the possibility that the winning design would be built.

Each team was able to use either synchronous or asynchronous communication technology as they wished. The paper analyses the types of communication which took place and notes that Team A ended up using primarily asynchronous systems (e-mail, ftp); Team B used synchronous (Timbuktu and ftp) while Team C communicated much less. The teams classified their communication into design and administrative communication.

The paper notes that asynchronous communication was very useful for administrative communication since Team A tended to engage in such coordination communication and tended to use e-mail heavily for this (Morozumi, et al., p. 150). It also notes that e-mail took half an hour between the USA and Japan so teams B and C activated video conferencing tools and kept them open continuously in the last week to overcome this time lag (Morozumi, et al., p. 151). Synchronous communication became difficult when network congestion reduced its usefulness during daylight hours in Japan (local network traffic increased after the vacations ended). The data presented show that Team A did not use video at all in this latter period, Team B supplemented video with desktop sharing. Team A used a bulletin board and found this useful for grouping discussion threads until the number of messages reached over 100 and refresh rates dropped dramatically. The paper suggests that the bulletin board, with its asynchronous nature and isolated as the user is from problems of network traffic, helped Team A conclude their work more efficiently than those teams which relied on synchronous communication.



The paper notes too that "each team made full use of the advantages of the video conference tool: first, speedy dialogues often stimulate new ideas, second, the countenances and gestures of the participants sent through video conference tool could improve the process of persuasion and bargaining essential to design discussions." (Morozumi, et al., p. 151). The paper concludes "After the project, the students expressed a strong hope for an interactive 3-D modelling tool that could support design communication through the network." (Morozumi, et al., p. 152).

**Lin & Wang (1997)** describe a single experiment — the design of a parking lot by two student teams, one responsible for landscape design and the other to design traffic flow. The two teams were located in the same building but used the Intel Proshare video conferencing system over the computer network to communicate. This tool allows "two users to have a video conference and to share a computer application" (Lin & Wang, p. 154) — the paper neglects to identify what other computer applications were used in addition to the video channel. The experimenters videotaped the scene in each room using a separate video camera pointed at the workstation. Two hours of video was recorded and analysed.

One team (Team A) appointed a 'negotiator' to conduct communication on their behalf. The other team (Team B) shared this role according to the topic under discussion. The paper notes this lead to Team A gaining an upper hand in the negotiations through the more extensive skills their negotiator achieved through cumulative experience in using the tools.

The paper places heavy emphasis on the development of tacit understanding (a concept inaccurately attributed to Scrivener, Harris, Clark, Rockoff & Smyth, 1993) and relates this to the achieved richness of non-verbal communication. They report that Team B broke the rule about face-to-face contact and participants walked over to the other room three times in the two hours in order to negotiate a solution. It should be noted that their communication set-up was very limited with only one video camera with the picture displayed on a computer screen. As such, it fails to achieve the four requirements for shared drawing activity as noted by Scrivener, et al. that marks and gestures are visible to all participants; rapid switching between drawing, writing and gesturing is possible; users able to mark, erase and gesture in same space simultaneously; and familiar mechanisms for drawing should be maintained (Scrivener, et al., 1993, p.268). While this experiment is not a synchronous drawing (in that the participants are not working on the same drawing),

The authors note that the physical layout of each room had a noticeable effect on the working methods of the participants and hence their success in using video conferencing. This does reflect the opinion of Scrivener, et al. that setting influences the outcomes of a synchronous collaborative drawing effort.

Although the experiment is itself interesting, the results of the experiment are thin, messy and consequently of little value.

**Fukuda, Nagahama & Sasada (1997)** present a system used for bringing the public into the design process by making design information available online. The system was used in a project with a designer in Osaka, a consultant in Tokyo and a site located in another city (identified as A). Design information was posted to a homepage in VRML format which could be viewed by all with web browsers. The results of the project are not fully presented (only one comment by a user is recorded) hence no meaningful evaluation can be made.

### **3.4.3 ACADIA**

**Cheng, et al. (1994)** describe the VDS'94 between the universities of Barcelona, MIT, Cornell, Washington University St. Louis, British Columbia and Hong Kong (also described in Bradford, et al., 1994 and Cabellos, et al., 1994). The paper notes that the lessons learned are:

1. the importance of socialization in the design process; and
2. the influence of media on the communication of designs (Cheng, et al., 1994, pp. 119-121)

Socialisation is described as needed in order for the participants to achieve a common understanding of the problem at hand. While socialisation is mentioned as essential, there is little definition or discussion about what socialisation actually is. "Socialization helps to focus the collaborative effort" (Cheng, et al., 1994, p. 120) is as far as it goes in the discussion. With the large number of participants involved, the need for identity was seen as particularly problematic. It was noted that communication occurred in a hierarchical manner: within the teams, within the sites, between the sites and at the video conference (1994, p. 120). The paper



does not demonstrate that the outcomes are affected by the degree of socialisation achieved.

Media are seen to affect communication of design by presenting the design with lack of clarity (resolution problems on monitors) or by making the images appear more final than they were. The paper also notes the desirability of a shared 3D model which participants could manipulate and annotate (VRML technology became available after this VDS was carried out).

**Fuchs & Martino (1996)** describe *V.C.net*, a database into which design projects can be placed. The database takes the form of a cityscape constructed on typical rectilinear North American planning principles, bringing the design results from disparate design studios into a 'city'. The paper describes V.C.net at an early stage of its implementation and offers no theoretical basis for the implementation nor critical evaluation of its capability. While the paper states that the database is "an Internet-based educational and communication tool for the architectural community" (Fuchs & Martino, 1996, p. 23) this assertion is not demonstrated by the results nor supported by the implementation. The only 'collaborative' feature of the system is the ability to see your own design within a context of models of design proposals by others.

**Knapp & McCall (1996)** describe a re-implementation of PHIDAS II (McCall, Bennet & Johnson, 1994) to support collaborative design by distributed design teams. PHIDAS is a hypermedia based CAD system which permits the linking of

CAD graphics, database content (including text, graphic and voice data) and knowledge-based computation. In 1994, the authors described the system and its future development at which time they did not mention collaborative applications as of interest. In 1996, they presented a redesign of the system as a two-part system: a server for the databases and a client interface. The system is implemented in JAVA and VRML, permitting the WWW to be used for communication. The communicative capabilities are limited to each client being able to access a common database of text and VRML images.

**Kalay (1997)** describes a three-component system to support collaboration. The three components are a product model, a performance model and a process model (hence P3) which are integrated into one unified framework. Notes that collaboration in a design team is a dynamic condition in which the actual participants will change from one phase to another. Notes too that sequential collaboration is costly (Kalay, 1997, p.193) due to loss of information, duplication of efforts, optimisation of subsystems at the expense of the whole and mismatches at boundaries. Kalay asks why collaboration which works well in other disciplines cannot be incorporated into the construction industry. Distinct professional boundaries and limited risk taking due to litigation push participants towards segmentation of the work. Most teams do not have a shared view of the end product. Each has its own value for the product — quality, function, making, maintaining.

In terms of computational support for collaboration, Kalay notes that it is easy to share a geometric description but more difficult to represent that rationale behind selecting a geometry. This semantic information is necessary as other participants consider proposed changes. Components of a building can be described factually, data which Kalay uses as one module of P3 (the *product* model). Factual information can yet be interpreted in different ways by different participants in the collaboration. He suggests that each profession may interpret facts in their own framework and embed these frameworks in their tools. These tools are the *performance* models of P3. He then notes that these product and performance models do not facilitate collaboration in themselves since they are static representations which do not support deliberation, negotiation and the dynamics of design itself. A *process* model is therefore needed to track design intents and decisions and support negotiation.

Kalay explains that the product model is implemented using object databases containing facts about the artefacts of the design. A project-specific database collects information specific to the project itself (as distinct from generic objects). The performance model employs agents (intelligent design assistants — IDA) to perform tests on the designs. The IDAs are limited in their ability, provided with semantic interpretation capabilities to interpret drawn inputs. The process model consists of an Issues database (where judgmental and professional valuations are kept) and a 'tradeoffs representation unit' in which compromises made along the way are recorded. These compromises are recorded in terms of 'satisfaction



ratings' for various aspects of design. The satisfaction ratings are set by the designer or client and composed for each aspect of design considered measurable and relevant.

The system is beginning to be implemented through individual components and mock ups of the overall system. The author asks how the design process might change if such a system exists. He notes that the intent is to support designers whatever way they work, not to create a prescriptive method.

### **3.4.4 Summary**

The long list above illustrates the diversity and activity within the field at this time. Before analysing the technologies, it is useful to summarise briefly some common themes.

From these papers, one can see an increasing interest in the application of virtual studios in the teaching environment. It is also obvious that most implementations employ technology which is at hand with little consideration to the implications of the technology. Commonly, the studios are created around a set of tools consisting of a CAD system to create models, a means of collaboratively sketching (typically a crude whiteboard paint programme) and a means of communicating messages. Often a video system is added to permit synchronous image and audio transmission. Typical of the evaluative comments is the following, made by students in Italy after their first VDS experience:

The "most interesting... is the possibility of building relationships among things, in this case documents and information, and among people... e-mail and

videoconferencing permit in the initial phase effective teamwork..." (Emprin, et al., 1997, p. 7)

From these reports we see little testing of system variables to understand the effect of technology on collaboration. While one reports experimental results (Lin & Wang, 1997), most VDS experiences are carried out with the technology at hand, supplemented by additional technology to transmit video and audio signals if not already available, and using whatever bandwidth is available. Only one of the papers (Morozumi, et al., 1997) presents any evaluation of the technology and its effectiveness although its evaluation of the usefulness of video is superficial. Chiu (1997) contends that the technology chosen affects the effectiveness and outcomes of a digital design studio but does not present a rigorous examination of this hypothesis.

Using the framework explored in Chapter 2, we can classify the work described in the papers into two categories, those which demonstrate primarily that they supported design as an experiential action and those which primarily supported design as a task environment (Table 4). From this review, we see that the majority of VDS explorations to date have been based on the assumption that collaborative design is an experiential action, an approach framed by the work of Schön.

Table 4. Approaches to VDS implementation

Supporting design as an experiential action	<ul style="list-style-type: none"><li>▪ Bradford, et al., 1994</li><li>▪ Cabellos, et al., 1994</li><li>▪ Martens, et al., 1995</li><li>▪ Dobson, et al., 1995</li><li>▪ Grant, 1997</li><li>▪ Lee, et al., 1997</li><li>▪ Martens &amp; Dokonal, 1997</li><li>▪ Emprin, et al., 1997</li><li>▪ Morozumi, et al., 1997</li><li>▪ Lin &amp; Wang, 1997</li><li>▪ Fukuda, et al., 1997</li><li>▪ Cheng, et al., 1994</li></ul>
Supporting design as a task environment	<ul style="list-style-type: none"><li>▪ Grootel, 1994</li><li>▪ Kusama, et al., 1996</li><li>▪ Comair, et al., 1996</li><li>▪ Woo, et al., 1997</li><li>▪ Fuchs &amp; Martino, 1996</li><li>▪ Knapp &amp; McCall, 1996</li><li>▪ Kalay, 1997</li></ul>

The VDS appear to embody assumptions about the nature of communication; most of the assumptions are based on the idea that design is "not just as a technical process... but also as a social process." (Mitchell, 1995a, p. 8). The nature of the virtual design studios are predicated on Schön's model, emphasising in particular the knowing-in-action experience of a student working to reveal the experience of designing in virtual collaboration. The assumption in some implementations appears to be that design is a situated act and that the technology must try to convey the context at each node to the other. It is clear that some of



those implementing virtual studios are willing to expend great effort and perhaps money to achieve this result.

Before examining the technologies used in detail, professional applications are reported.

### **3.5 Professional experiences**

In addition to the educational applications described in the research papers above, the architectural professions have been very active in exploring and applying networked communication to support their work. Many of these explorations have been reported in the professional journals, the more interesting examples of which culled from professional journals in recent years are presented here.

- Day (1993) records how practices using computers are changing the layout of the design studio and the operation of their practices. Day notes how a CAD system allows a practice to carry expertise from one project to another more readily than in paper form, making data accessible to multiple users. The report records details of the way six practices operate: Lord Aeck & Sargent; Gensler Associates; Page & Turnbull; Anschuetz Christidis & Lauster; Interactive Resources; and Anshen + Allen. These practices have changed the layouts of their offices to permit focus on client and project needs and not on administrative requirements of the work.

- A report on virtual practices ("Virtual A/E firm", 1994) identifies Wayne Architects, Greenwich, Conn., an eight person practice of whom four work from their homes. The team members meet about every ten days to compare notes and co-ordinate their work but otherwise rely on modem connections.
- Novitski (1994) describes early laboratory-based experiments to integrate multi-disciplinary project teams, then in a later report (1996) reports how practices from four persons to over one thousand use communication technologies to bring designers, consultants, clients and projects together. She identifies benefits for small practices, allows them to bring more expertise together as needed for particular projects; makes them "more fleet of foot in satisfying the needs of our clients" (Novitski, 1996, p. 46). This article further reports how Eric Owen Moss used mixed communication technologies of video-conferencing, shared displays and voice connections to design in a team between France and California. Moss remarks "... however dextrous the software is, there is still something imponderable in the content of the work, which architecture will always be about." (p. 49).
- Phair (1996) tracks the move towards enterprise computing is affecting CAD. The author suggests that this is encouraging practices using CAD to look at client/server applications with shared CAD databases but does not detail the means and extent of sharing.

- Laiserin (1996) describes the current state of art in practice by using the work of four practices: Zimmer Gunsul Frasca Partnership, Gwathmey Siegel & Associates, Skidmore Owings Merrill and Kohn Pedersen Fox Architects and Planners. He records examples of computer use in collaboration, both face-to-face and distal. The examples are all supporting communication or passing files asynchronously.
- Savage (1996) writes "with wireless communication and the Internet, "virtual offices" blur the distinction between what is the "main office" and what is the "job site". The item describes how job site staff of NorthWest Cascade (an electrical utilities contractor) and The Sverdrup Corporation use document management systems to remove substantial paperwork from their work. The author notes that Winter Park Construction Company uses video cameras to record site activities 24 hours a day which is then transmitted back to a web browser for monitoring job progress.
- Phair & Angelo (1997) note that their survey of practices in the construction industry found only 11% of computers having Web browsers installed, with design practices leading at 20%, speciality contractors at 12% and general contractors at 3%. Use of Web pages for project communication is more widespread." An average of 19% of all respondents report creating one or more project Web sites." Design practices lead again with 42%, contractors 29% and speciality contractors 20%.



- Ross (1997) the article details how to set up web-based CAD collaboration, exchanging files by ftp or using web plug-ins such as WHIP! to view DWG files. Identifies several practices which currently use these technologies. Ross identifies the benefits as:

"Computer networks, particularly the Internet, have made it easy and cost effective for architects, other design professionals, and even clients to work together even when they are apart.

"Obviously, the design process is accelerated if professionals can exchange documents more quickly or work on the same documents at the same time... Less obviously, more documents get exchanged when you use CAD and collaborate over a network, and they get exchanged (and in the early design stages, modified) more often." (Ross, 1997, p. 131)

- Sanders (1997) notes the move by practices ZGF, Gensler, HOK, NBBJ, and Callison to set up their own Internet and Intranet systems. He suggests that the value of the implementation must be measured by the quality of services produced using the information available. "... a good internet contains not only endpoint information, but also pointers to the right people — those who possess specialised knowledge or experience." (Sanders, 1997, p. 125)
- It is reported ("ZGFNet", 1997) that Zimmer Gunsul Frasca Partnership has implemented an Internet link between four offices which they have called ZGFNet. Using SQL database support, they store project information for searching from any location. A CAD library database is accessible for drawing information. Video cameras feed information back from construction sites to aid in monitoring project progress. Staff working on job sites have access as do those in the four offices and also 30 clients.

These reports show a developing sophistication and growing application of web-based communication in professional practice. Within the framework of CSCW research, the applications are all providing communication support, defeating distance and time.

The technologies used in educational and professional applications can now be examined in detail.

### **3.6 Technologies employed**

This section reviews technologies actually used in virtual design studios or collaborative design exercises and classifies them into the categories proposed by McGrath and Hollingsworth as described on page 112 above. The examples are drawn from the review of papers and professional applications presented above to illustrate the technologies and their use.

#### **3.6.1 GCSS / GXSS**

The majority of work reported in collaborative design activity focuses on the communication between participants, that is, in overcoming the space and time constraints of the collaboration. Examples of technologies we see being used in computer-supported collaborative design are:

- E-mail (Dobson, et al., 1995)
- Asynchronous “pinup board” (Wojtowicz, et al., 1992; Bradford, et al., 1994) — this is not GISS tool since the files are merely being passed

between participants. The pinup board does not structure the data or provide search tools to assist the user to find pertinent data.

- Asynchronous communication for design decision making (Emprin, et al., 1997)
- Shared whiteboards (Cheng, et al., 1994)
- Synchronous video-based communication (Dave, 1995)
- Full video, audio, whiteboard environments (Tang & Minneman, 1990)
- Combining remote design juries (Grant, 1997)
- Structured design exchanges (Chiu, 1995)
- Face-to-face meetings supplemented by bulletin boards (Martens & Dokonal, 1997)
- Interactive exploration of VRML models (Kusama, et al., 1996; Martens, et al., 1995)

Unlike the communication applications examined by Kraemer & Pinsonneault, the technologies employed do not provide any structure to the exchanges. Rather than providing any specific facilitation, they are technologies to *enable* communication. The tools deal with some specific issues encountered in design communication which may not arise in the communications of other studies, specifically the communication of graphic information (for example, whiteboards) or the design process (design juries).



### 3.6.2 GISS

The sharing of data is central to collaborative design. Several papers report experiences or methods for achieving this. Kimura, Komatsu & Watanabe (1995) have developed an Interapplicative Collaborative Design System (ICDS) to merge data from the many participants in planning. Similarly, McCullough & Hoinkes (1995) describe the dynamic data sets created during collaborative urban design and means to share them. Lee, et al. (1997) share models between locations although the primary use is simply communication between participants in the design — the role of information database access is very minor. At this level, however, the systems are not co-ordinating data or providing it when needed by the users. More extensive use of an information exchange is seen in Comair, et al. (1996) in which formal participants in the project can access shared information but, more interestingly, so can informal participants — the general public. A similar application appears to have been made in Fukuda, et al. (1997) although the paper is vague about its actual implementation and use.

Useful research has been carried out by several authors (Saad & Maher, 1995; Kalay & Séquin, 1995; Grootel, 1994; Jabi & Hall, 1995; Khedro, 1995; Kimura, et al., 1995; Kalay, 1997) who have looked at the technical issues which arise in implementing tools for sharing information. The key issues are whether the data are shared or simply passed around between participants; how multiple versions are maintained; avoiding the loss of semantics in the data (what did something mean when it was drawn); and permitting users interested in different aspects of

the project to see the data in their own terms (for example, the difference between an engineer's and an architect's views of a building). These issues are discussed further in Chapter 4 below.

Some systems go beyond simply storing data for multiple access by attempting to develop tools to provide data intelligently either in anticipation of the user's requirements or as agents working on behalf of the users. Khedro (1995) presents a system called AgentCAD which co-ordinates communication of design information between participants, some of the communications being anonymous if desired. Similarly, Vervenne, Rogge, Van Laere & Vandamme (1995) propose the use of agents ("Annot Agents") to co-ordinate and facilitate the communication of annotations between users. Their description is no design related and appears to be unimplemented.

### **3.6.3 GPSS**

With the exception of Kalay (1997), most implementers of design support tools appears to have ignored largely the ability of CSCW tools to provide structure to performance processes. The absence most likely reflects a prevailing in attitude to architectural design noted in Chapter 2 in which design is seen as a social interchange which defies structure. This shift from activity-oriented design to process -oriented documented in Dorst & Dijkhuis (1995) has moved computers from tool-focussed to process-supportive. Thus it is not unsurprising that we find very few tools structuring the design process and channelling communication in a collaborative design systems.

### **3.6.4 Integrated systems**

Most implementations described in the papers and reports address GCSS and one other aspects of McGraw and Hollingshead's model. The various components are typically not integrated. The P3 system (Kalay, 1997) is the only system reported to date tightly integrates two components of McGraw's model: a product model (GISS), and a process model (GPSS) which are integrated into one unified framework. In addition, P3 provides a performance model which is a decision support tool which falls outside McGraw's model (GDSS). It should be noted that P3 does not address GCSS/GXSS features in any way.

### **3.6.5 Benefits accrued**

Few of the explanations of virtual design studios or collaborative architectural design exercises enter into much detail about the qualitative aspects of the outcomes. Most explain the efforts undertaken and make generally reassuring, but unsupported, words about the usefulness of the experience (for example, "the design projects developed by students are qualitatively acceptable... networked studios are a good vehicle to educate Dave 1995, pp. 663-4). The one benefit documented is explained in Morozumi, et al. (1997) in which they note that one team (Team A) abandoned the synchronous video environment and used e-mail and bulletin boards only for their exchanges. The paper suggests that the bulletin board, with its asynchronous nature and isolated as the user is from problems of network traffic, helped Team A conclude their work more efficiently than those teams which relied on synchronous communication. This positive process benefit



is not one arising from a process structure imposed by the system but the realisation by the users that the technology would benefit from a structured application.

### 3.7 Discussion

As McGrath and Hollingshead (1994) have observed, research in the field of CSCW remains within the confines of three basic areas of interest: improving group task performance; overcoming time and space constraints on group collaborative efforts; and increasing the range and speed of access to information. Reviews of the outcomes of research support the contention that computer-mediated communication tools can improve group processes and decisions. There is therefore a reasonable understanding of the mechanisms of computer-mediated communication and a basis on which to interpret the results of its use.

From the review presented in this chapter, it appears that research into CSCD is even more limited in its interests than the work in more general CSCW systems. The bulk of the work to date has focussed on only one of the three areas defined by McGrath and Hollingshead, that of providing GCSS/GXSS tools to overcome time and space.

Why might this be? Perhaps it is that time and space are the daily concerns of architects (Giedion, 1941). Perhaps it is that tools which improve group task

performance seem too prescriptive and out of sympathy with the broad perception of architectural design as an ineffable act which defies process improvement.

Whatever the reasons, the focus has been limited. There have been few systematic efforts to identify either process or decision improvements which arise from applying decision support tools or process structure tools to design. Even in the field of communication support, the studies have generally been limited in their usefulness. Often they are very limited in scope, with a very small number of participants (for example, Scrivener, et al., 1993). More often, the research simply reports on an experience and offers subjective comments without examination of the conditions or conditions which influence the outcomes (almost any example from the conference papers summarised above, such as Wojtowicz, et al., 1992).

The observation of CSCW by McGrath & Hollingshead holds true also for CSCD, namely:

The study of group support systems has been much more about technical developments and applications than about identification and exploration of basic theoretical issues involving the functioning of work groups.... There has not been much effort given to formulating systematic, integrative conceptual frameworks that would serve as guiding perspectives for future research. (McGrath & Hollingshead, 1994, p. 1)

There is substantial room for further investigation. The steadily increasing intersection of computers and communication offers new opportunities to look again at the processes of design and examine our understanding of architectural design itself. To date, most implementations have either implemented technology at hand or they have uncritically accepted the view that design success stems from social interaction and engaged in expensive videoconferencing (e.g. Bradford, et

al., 1994; Grant, 1997; Martens, et al., 1995). Some who have developed tools (e.g. the substantial body of work coming from the Sasada laboratory at Osaka University, reported in Kusama, et al., 1996, Comair, et al., 1996, Kaga, Comair & Sasada, 1997, Lee, et al., 1997, Fukuda, et al., 1997, Woo, et al., 1997) go to great lengths to implement tools to mimic face-to-face interaction using for example avatars in VRML. Other tools ignore the need for personal communication (e.g. Morozumi, Murakami & Iki, 1995; Kalay, 1997; Murakami, Morozumi, Iino, Homma & Iki, 1997).

### 3.8 Conclusion

Grounded in Schön's action theory, implementations of CSCD to date have, for the large part, focused on simulating "being there". Building on situated action theory, most CSCD environments have emphasised communication of presence. Unlike research in CSCW, efforts in CSCD have not undertaken a systematic exploration of the potential benefits of computer-mediated communication. The bulk of CSCD work reported remains anecdotal and hence flimsy evidence for developing computer environments for CSCD, even if some of the findings (such as Morozumi et al., 1997) offer interesting glimpses of potential process benefits. The benefits of video communication, in particular, have not been demonstrated. Integrated CSCD environments, such as Kalay's P3, emphasise the close coupled nature of collaboration inappropriately. As such, there has been no development



of theoretical frameworks in which to examine CSCD potentials and opportunities.

Research into CSCW has postulated that computer-mediated communication can offer benefits through improved process structure, greater participation and better results. There is a need for research to systematically examine these potentials and discover if they hold for CSCD. Remembering that design is a loose coupled process, it is most likely that we will find different benefits arising at different stages of work. The nature of design and its communication needs to be examined in controlled conditions. For example, since most CSCD environments today are developed on the assumption that verbal and non-verbal communication is essential for social interaction, demanding high bandwidth support, this thesis specifically examines this aspect of design collaboration in Chapter 5.

## **4 Tools for collaborative projects**

There is a wide and ever-changing range of technologies available to a team implementing collaborative design. Telephone companies, hardware and software companies and internet providers all see the communication over the net as a field of great opportunity. The particular technologies we use in supporting design collaboration must support a variety of activities in order to accomplish a design studio. While the particular tools may change frequently, the basic technologies do not and the principles on which the technologies are based change less frequently. Thus in this chapter we will consider the principles and issues which lie behind the technologies and their application. These principles provide the basis on which choices for which particular tools can be made.

It is natural to consider the resources needed to support CSCD as being computer tools. As the previous chapters have illustrated, however, the resources will need to be more than hardware and software in order for the processes outlined above to be successful. Obviously the *expertise* of the participants in both their technical fields and in collaboration will be important. Since it is unlikely that a team can be assembled with a complete and thorough knowledge in the areas of project relevance, *training* will also be an important resource.

Computer tools required to support collaboration must enable participants to send and receive information in some form (written, spoken, drawn) to one another. They must be able to represent their designs online. These must then be shared, either by being transmitted or open simultaneously. Files have to be stored for later access. User access has to be controlled in order that non-participants do not invade the sessions. Finally, the technology must support the review process which is integrally a part of design. The range of technologies used to support each of these aspects is described below.

## 4.1 Tools for communicating

Four communication technologies are typically associated with collaborative design systems: typing, audio, video and drawing. In this section, we will consider the role of each and report findings from key papers related to the application of the technology.



### 4.1.1 Typing

Computer interfaces are now typically oriented around text. The keyboard is the normal input mechanism, and reading the common output interpreter. We have come to accept this as the norm, although as computers and communication intersect more we are encountering audio and oral interfaces more often. Those who use computers, however, are not surprised to encounter a keyboard.

Only a small part of design activity can be conducted using a keyboard and text. Drawings remain important and graphics therefore essential to collaborative communication. Text nevertheless plays a necessary part in the communication and recording of transactions. Architect's offices use text in many ways, such as letters and memos from clients and consultants; meeting minutes; specifications to tell contractors what to build; and written words documenting design ideas.

Text can be employed in a number of ways in computer-mediated collaborative work. E-mail is a simple method of sending a text message from one person on a network to another. E-mail has the advantage of enabling distribution lists, in which a message can be sent to many people with as much ease as to one. Although asynchronous in nature, it can be used by teams in a rapid manner which approaches synchronous exchanges.

Much like a physical bulletin board on which paper can be pinned, electronic bulletin boards are places in which text messages can be stored for review by all with access to the board. Messages are accessed by thread, the subject headers

under which the messages are posted. Variations on this can be found, such as HyperMail in which e-mails are posted in a web interface for the group to read.

Chat lines are synchronous text exchanges between two users. If more than two users are engaging in a synchronous text 'conversation', the exchange is likely to be held in a MUD or a MOO. In these settings, messages are posted to a screen when the user has completed typing their text and pressed 'Enter'. The message is identified with their name (or nickname) so others can follow who is saying what.

It has been shown that text enhances comprehension of a message. When comparing written and oral comprehension, Hildyard and Olson conclude that listeners pay primary attention to the theme of a story, building a coherent representation of what was meant. Readers pay closer attention to meaning of sentences and details (Hildyard & Olson, 1982). Furthermore, a good typist can only output around 60 words per minute while a good talker can output over 180 words per minute and handwriting averaging 13 words per minute (Chafe, 1982, p. 36). Writing affords more time to think of the content, while refinement of the message is further supported by editing capabilities. Thus a written message can be more complex and integrated than a spoken one (Norman, 1993; Chafe, 1982). This capacity to review and edit also allows written communication to be more efficient than spoken, word for word. Spoken conversations are replete with repetitions and clarifications arising from poorly phrased or incomplete utterances. The participants must mutually arrive at a shared understanding of the exchange, a 'grounding' process (Clark & Brennan, 1991). Spoken conversations

are subject to three factors which contribute to confusion and the need for grounding: time pressures, ignorance and errors. In spoken conversations, we often hear people speaking incomplete sentences and together moving toward an understanding of the subject. Clark & Brennan note that more individual effort is required to utter a precise and clear statement than the perceived effort for those conversing to work together to arrive at a shared understanding. Written exchanges need less grounding since they occur with less time pressure and affording an opportunity to think while writing. An exception to this has been observed by Easterbrook (1996) when responses to e-mail are made immediately, often leading to "flaming" and highly emotional exchanges.

Electronic mail creates communication with no shared physical setting and fewer group norms, formalities or exclusionary behaviours (Finholt & Sproull, 1990). They note that e-mail groups can grow to be very large through the use of distribution lists (over several hundred participants) yet still exhibit the characteristics of small group behaviours. Thus, text messages are enabling members of groups to behave in more inclusionary and egalitarian ways than face-to-face meetings would permit. In addition, other benefits can be accrued from digitally created text communication which non-digital textual systems (such as fax) do not provide. Digital means of communication allow for editing or messages, channelling of information and the use of databases to store and retrieve the text (Kiesler & Sproull, 1992, p. 97).



Social cues play a part in communication, allowing some participants to dominate over others by virtue of their social, gender, age, race, or vocal characteristics (Giles & Street, 1994). Because text does not have the ability to convey as many social cues as voice or vision, textual messages are seen to be a means of social equalisation. This outcome is seen in several studies of e-mail and text message exchanges in CSCW (Sproull & Kiesler, 1991; Siegel, et al., 1986; Easterbrook, 1996). Cues are useful however and written messages do contain their own, enough to enable the reader not to become confused by the protocols of exchange.

#### **4.1.2 Video**

Video systems enable the participants to see one another (Morozumi, et al., 1997), to participate in shared experiences such as lectures (Grant, 1997) and reviews (Shelden, et al., 1995) or to observe remote sites or artefacts such as drawings or models (Cheng, et al., 1994).

Video can be implemented as monitor-based video images using common technology desktop video cameras which can be turned on or off by users as they wish, such as CuSeeMe or Silicon Graphics InPerson (Wojtowicz, et al., 1995, Morozumi, et al., 1997, Dave, 1995), custom video systems for on-screen viewing (Tang & Isaacs, 1993), multiple cameras on a workspace, displayed on dedicated monitors (Harrison, et al., 1997) or large scale video images which provide open video streaming of activities such as the Media Space at Xerox PARC (Bly, et al., 1993, Harrison, et al., 1997, Abel, 1990).



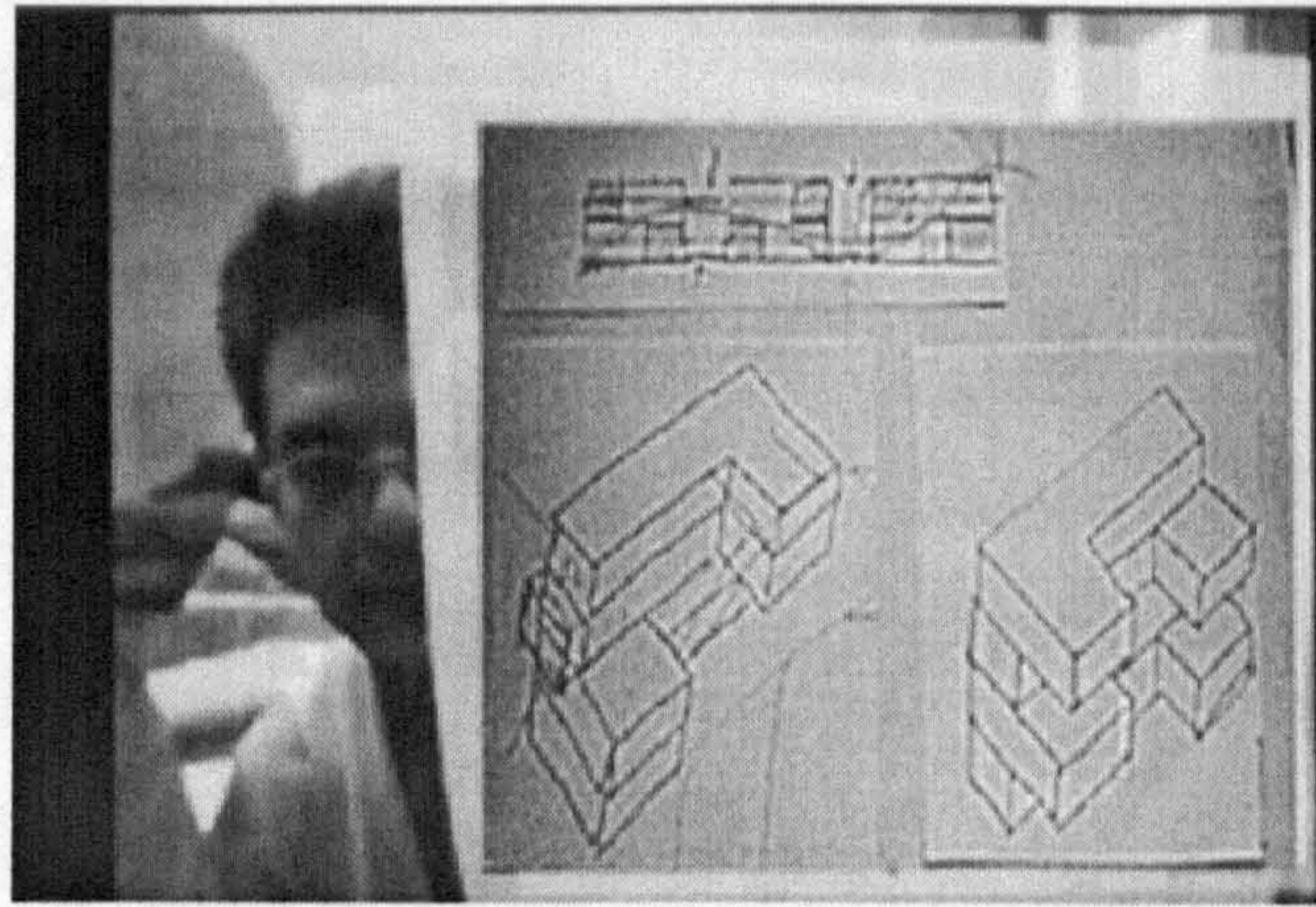


**Figure 10:** Multiple video windows in a VDS

Video outputs a considerable volume of data, even when compressed. Bandwidth is therefore always an issue when considering video connections. The data output can be reduced by reducing the image size, reducing the image quality (such as pixels per inch or number of colours) or reducing the rate at which the image is refreshed (the frames per second or fps — television has 25 or 30 fps, depending on the encoding convention employed). A reduction in quality has concomitant reductions in the amount of information transmitted and hence the usefulness of the image received. If you simply want to know if there is someone present in another room, an image of 2 cm. by 2 cm. in black and white is adequate to detect a presence. If you wish to show someone a detail on a sketch which you are holding (Figure 11), such a small image will be inadequate to convey the result. Unfortunately, the experience of most users of live video received over a network is very poor, engagingly described by *The Economist* as:

The tiny images are like demented postage stamps coming jerkily to life; the sound is prone to break up and at times could be coming from a bathroom plughole. Welcome to the Internet live broadcasting experience. ("Loopy.com?", 1998)





**Figure 11:** Holding up a sketch (VDS 94)

#### **4.1.2.1 Supporting conversation**

The need for video to support communication stems from the understanding that much of communication is non-verbal. A common assumption is that only 7% of the meaning of an exchange comes from the verbal component of the communication, although it is now accepted that meaning is attributed to 31% of verbal content with the balance presumed to come from non-verbal (Burgoon, 1994, p.234). Thus it is assumed that video must be used to support communication. Furthermore, in an activity such as design in which the visible is an integral part, video is assumed to be yet more important.

As noted by Whittaker and O'Conaill, the four communicative acts supported by vision are gaze, facial expression, gestures and posture. These each in turn support process co-ordination and content co-ordination during a conversation (Whittaker & O'Conaill, 1997, p.28). Their paper identifies the fundamental features of communication that have to be supported in a conversation and the role of visible information in this communication. Using this framework, they evaluate three



predictions of video-mediate communication: that it supplies non-verbal information missing in the speech channel; that it supports unplanned communication; and that the video stream itself is data, conveying information used in the task itself.

Most findings relate to high quality video connections. While contributing non-verbal content, Whittaker and O'Conaill note that there is little impact of this visual information on cognitive problem solving even when using high quality connections or face-to-face (p. 37). Turn-taking was not better supported by audio-video (A/V) systems than simply audio, although they note that more research is needed. Satisfaction is higher — groups using audio and video tend to like each other more (Whittaker & O'Conaill, 1997, pp. 37-38).

There is also the suggestion that the availability of video during design makes for easier discussion of critical issues. Whittaker & O'Conaill (1997) note that A/V supports the transmission of social cues and affective information, thus changing the outcomes of tasks requiring emotional or affective factors such as negotiating, bargaining and conflict resolution. As already mentioned earlier, Morozumi, et al. (1997, p. 151) noted that one of their teams left their video channels open throughout the design period of two weeks and in their debriefing reported that it was particularly useful in negotiation. It is not clear from their report exactly what the video was used for and how this use supported negotiation between participants in the two locations. We should note that research is not clear on how broadly this outcome is supported. A survey of the literature (Whittaker &

O'Conaill, 1997, p. 38) concludes that participants focus more on the motives when visual information is provided and that the negotiations are less likely to end in deadlock than when only using audio. On the other hand, Nunamaker, et al. have found when using computer tools to support negotiations in military, political and commerce that tools which allow for anonymity and use only text support better negotiation (Nunamaker, et al., 1995). Reid (1977) concluded that voice only contact was far better than face-to-face encounters when the goal of negotiation was to change the listener's opinion of the other person. There are as yet no studies which have examined the question of negotiation in design, whether face-to-face or computer-mediated. The contention that it is better via a video-supported connection is untested.

Users employing low quality video find that the video does not support their conversations, introducing problems in turn-taking and reducing its effectiveness to information exchange (Whittaker & O'Conaill, 1997, pp. 39-40). With limited bandwidth, a trade-off must be made between types of data being transmitted, for example between audio and video. Tang and Isaacs note that video conference rooms suffered from problems of audio collisions, difficulty in directing attention of remote participants and diminished interaction. Users were very disturbed by even the smallest synchronisation delay in audio behind video and that users preferred to disconnect audio from video, use the telephone for audio and thus receive audio before the video. The conclusion drawn is that receiving audio *after*

video was unacceptable but receiving audio *before* video was acceptable (Tang & Isaacs, 1993, pp. 169-170).

#### 4.1.2.2 Simulating collocated offices

Another application of video is to overcome space and to bring together collaborators in distant locations into one 'virtual space'. The most extensive example of this is in the Xerox PARC Media Space experiment, documented in Harrison & Minneman (1990), Abel (1990), Bly, et al. (1993), and Harrison, et al. (1997). In this example, two Systems Concept Labs of Xerox, one in Palo Alto, California, and the other in Portland, Oregon, were connected together with video and audio links which were left open at all hours to enable those working at one location to see activities at the other. Initially the links were only between the commons areas — the open lounge area situated in the middle of the work space and around which all offices were arranged. Later, the links extended into individual office areas.

As Bly et al. note, the reasoning behind this application is

"Our research is based on the premise that work is fundamentally social... Technologies to support collaborative work are defined by the social setting and by the nature of work, as well as by the features of the technology" (Bly, et al., 1993, p. 30)

Abel's paper documents organisational and behavioural changes which arise and social issues which became apparent as users came to live with connections to remote collaborators (Abel, 1990, pp. 496-503). It is interesting to note that in none of the papers describing the Media Space is any evidence offered to support



the notion that the outcomes of the work is in any way improved by such connectivity. After reviewing the literature on the subject, Whittaker and O'Conaill find the results are weak and there is little to support the hypothesis that video supports availability or information for unplanned interactions. In particular they note that open links between commons areas do not support work (Whittaker & O'Conaill, 1997, p. 42).

Similar to simulating collocated offices, video can be used to simulate collocated lectures or design reviews (Shelden, et al., 1995; Grant, 1997). This is more difficult to accomplish as the image must be of higher quality if the remote participants are to benefit from the video image. Architectural lectures typically consist of several media such as slides or drawings as well as speech. Grant notes that they had to employ professional video camera operators and technicians from the local television station in order to attain the appropriate quality. The orchestration of such live feeds is noted by both papers as being a substantial and very important issue.

#### **4.1.2.3 Video as data**

It is postulated that the video images themselves may function as a stream of data integral to the task in hand and therefore video is contributing not as an aid to the conversation but in its own right. This role of video is described in Nardi, et al. (1997) in which the authors examine the use of collaborative multimedia systems for co-ordinating teamwork in a neurosurgical team, the authors investigate the extent to which video is itself data for a task. Their conclusion is that video can be

a tool for analysis and problem-solving. Specifically, the video allowed team participants to co-ordinate their actions. The video also helped to disambiguate other types of data through observations about physical actions being undertaken that time; video displayed the physical state of the activity, allowing participants to enter into the activity at appropriate moments; and the image is useful for learning and education, allowing non-participants to engage and learn from the experience.

There are parallels to be found between the descriptions of neurosurgeons at work and designers at work. The actions and activities of the surgeons conveyed by the video link to waiting consultants is evocative of the participation of team members in a design charrette when one person takes dominant role in the design activity and others observe, each waiting to contribute their particular expertise.

#### **4.1.2.4 Synchrony and bandwidth**

The bandwidth is a consideration in video since a video signal consists of considerable data even when compressed. Video animation operates at 24fps or 30fps — slower than this and the image starts to jump in front of our eyes. The system described by Tang and Isaacs was used over a dedicated link between two remote sites offering 0.5 megabits/second (Mbit/s). When operating at 30fps, the set-up consumed 1.6Mbit/s of network bandwidth. At 10fps video the configuration could be used on local networks without disrupting other network traffic. In order to operate on the available link, video was set to 5fps although users could change this (Tang & Isaacs, 1993, p. 175). On top of these data we

then have to add the audio, text and graphics being communicated between users. As bandwidth fills, the problem will be seen first in the video link since the user immediately notices any delay in picture transmission. Breakdowns in the other kinds of data are less noticeable or disturbing to a user.

#### **4.1.2.5 Value derived**

Does video add value to a collaborative activity? Some evidence has been presented to support this claim. Olson, et al. (1997) note that in intellectual work (the drafting of product specifications as an assignment in an MBA course) high quality outcomes were obtained in face-to-face, video and audio and audio only collaborations, although the results from audio only groups were marginally worse than the others. The greatest difference was found in the *perceived value* by the participants — those working with only audio connections found the process less satisfying than those supported by video (Olson, et al., 1997, p. 170). This is similar to which reported that groups using audio and video tend to like each other more (Whittaker & O'Conaill, 1997, p. 38)

Tang and Isaacs found similar perceived results. In their study, users thought video delivered added value but, the authors note, it did not improve the product. They then postulate that because of this, the product could be better if the interaction is a long term one, but they offer no data to support this postulation (Tang & Isaacs, 1993, p. 193).



The results in architectural design collaborations is similar. In one of the few examinations of various modes of exchange, Morozumi, et al. found satisfaction in team members being able to see one another, but found too that the most effective team (out of three compared) used e-mail and not video and audio for their communications (Morozumi, et al., 1997). Thus the real contribution of video to computer-supported collaborative architectural design is a question to be answered, which this thesis answers in Chapter 5.

### **4.1.3 Audio**

Audio collaboration is the simplest and most familiar of all the technologies. The audio links we can use in a design collaborations include the telephone but extend to microphone/speaker configurations other than over dedicated dial-up connections. The Internet telephone and Internet audio links are also available as technologies to support design. These different means of connection do have important different attributes which affect the ways in which they can be used.

Such is our experience with telephones that we have little problem using audio to speak with remote participants we cannot see. It is interesting to be reminded that when the telephone was invented such uses were not considered possible. Indeed, Alexander Bell and his backers had to actively strive to discover applications of the technology and then convince others of their use (Pool, et al., 1977; Aronson, 1977). Its initial application was envisaged as a central broadcasting, bringing music into the home (Pool, et al., 1977), what we now call "push technology". It

was only later that its transformation as a tool for casual connection and conversation came to be.

As the example of the telephone tells us, anticipating the effects of technology is difficult. Kiesler and Sproull distinguish between first and second level effects of a technology, where first level are planned effects and second level are the unanticipated consequences. Second level effects arise from use, not from the technology itself in isolation. The second level effects of the telephone were its extension of social contacts, attention and interdependencies which extend beyond physical proximity (Kiesler & Sproull, 1992).

What about the disconnection between voice and image? Alexander Bain (a Scottish inventor working on the telephone about the same time as Bell) anticipated this problem in a patent filed in Britain in 1843 (predating Bell's telephone) in which he described the transmission of pictures across a distance (Pool, et al., 1977). Research into the application of the telephone in the period 1970-1975 examined this question carefully. The research used telephones, television and videophones as means to transmit voice and image in the course of carrying out problem solving activities under controlled conditions. Reid's survey of this research (Reid, 1977) concludes "the benefit of adding a facial display to the telephone will be very small indeed." (Reid, 1977, p. 411). He notes that the absence of visual contact with the other party appears to have "no measurable effect of any kind on the outcome of the conversation" in information transmission or problem-solving conversations (Reid, 1977, p. 411). In situations

of conflict resolution, however, he concludes that a visual channel does have an effect although he qualifies this by noting that the effects are small. He continues with the observation that in some conflict or negotiation situations in which the objective is to change the listener's opinion of the other person, a voice-only contact may be preferable.

In spite of this extensive history and familiarity with the technology, and conclusions that there are benefits which can be derived more cheaply from audio only, no VDS implementations have used audio only connections to support design. Audio compression technologies are more rapidly becoming effective than video compression technologies. There are a number of technologies available for audio transmission over the Internet such as I-phone, a two-way communication system which uses the telephone analogy, or RealAudio which uses the radio one-way broadcasting analogy. If transmission speeds are problematic, the M-bone technology can be used to support transmission. This latter accommodates different speeds of transmission to different nodes during the same broadcast, making it suitable to send lectures to several points on the Internet simultaneously.

#### **4.1.4 Drawing**

While CSCW systems intended to support general office work or other intellectual application may use shared graphic windows (such as in Tang & Isaacs, 1993), the need in a collaborative architectural design system is different. In the other applications, the shared graphic window is used to mark up texts or create unstructured graphic images (doodles) to convey information, these graphic marks



being tangential to the outcome. In architectural applications, the graphics are the data and thus graphic tools are central to the act of communicating.

That drawing is essential to architecture is self-evident. At all stages of the project, from earliest ideas to the completed design, drawings are the means of communicating an idea to the other participants in the design process. The act of drawing, however, has more importance than simply telling someone else what it is the designer is saying (Arnheim, 1996).

Architects make the same observation: "We explain through doodling." (Edward Cullinan in Robbins, 1994). Cullinan explains that doodling is a means of testing an idea and is used both in early stages of the project as designs are conceived and later to explain ideas when designs are more evolved. Doodling is also an act in collaboration. Cullinan again explains "our engineer told us how to make the roof for the Barnes' Church one afternoon just by taking a notional plan and doodling over it." Robbins, 1994, p. 64).

While doodling may be said to be tangential to the outcome of general intellectual work, it has been shown to be central to the creative thinking (Freyd, 1994) and an integral part of the cognitive problem solving process in design (Goldschmidt, 1994; Goel, 1995), not just as externalisations of thought by providing context and structure to the design process itself:

External representations e.g. diagrams, sketches, charts, graphs and even hand-written memos not only serve as memory aids, but also facilitate and constrain inference, problem-solving and understanding (Suwa & Tversky, 1997, p. 385)

Drawings also allow us to say things which are difficult to express in words (Larkin & Simon, 1987). While words require a sequential expression of ideas, graphic images allow for ideas to be expressed locationally. Larkin & Simon conclude that diagrams can be superior in a problem solving context to verbal descriptions for three reasons:

- Diagrams can group together all information that is used together, thus avoiding large amounts of search for the elements needed to make a problem solving inference
- Diagrams typically use location to group information about a single element, avoiding the need to match symbolic labels.
- Diagrams automatically support a large number of perceptual inferences, which are extremely easy for humans. (Larkin & Simon, 1987, p. 98)

Schön takes the act of drawing one step further. He refers to the architect having conversations with the drawings (Schön, 1983; Schön & Wiggins, 1992). Through the act of making ideas external and tangible, the ideas gain a role in the evolution which is not obvious from an internalised debate. Thus the action of drawing gains a central role in the activity of design which is beyond that which doodling or sketching holds in other forms of intellectual work.

There are a wide variety of tools available to support the process of drawing and sketching in computer-mediated collaborative design. Peng (1994) provides an extensive review of drawing tools for collaborative drawing, looking both at reports of tools in use and a classification of features and capabilities which might be useful. Perhaps the most commonly used tool is the whiteboard, similar to a paint program in its functionality and similarly limited in its capabilities. The reasons for its popularity are that it is easy to use, unstructured in its operation and

readily available in commercial groupware programmes such as Microsoft NetMeeting.

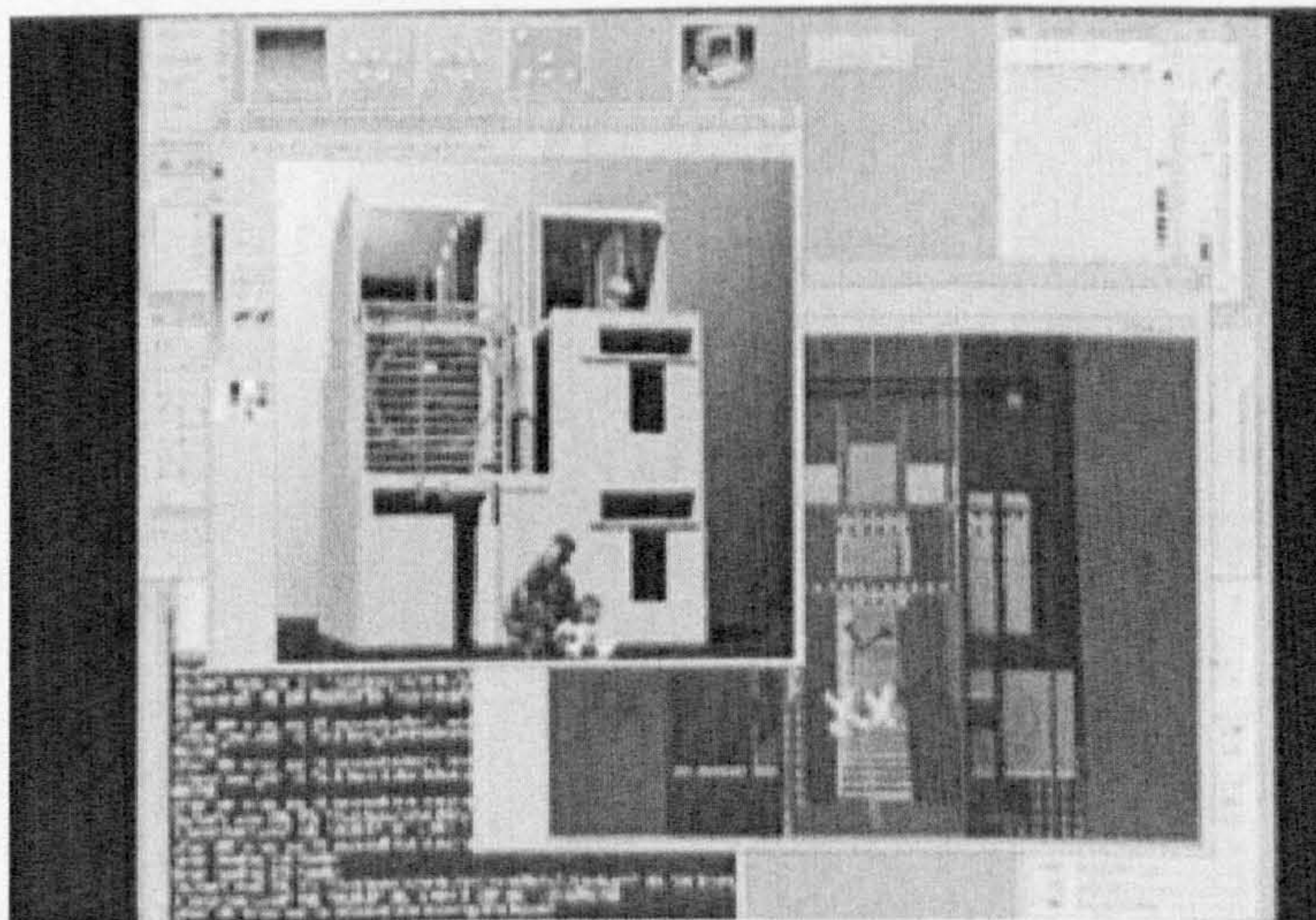
Some CSCD implementations have felt the need to provide more sophisticated drawing or drafting capabilities and have been implemented using computer-aided drafting (CAD) programmes overlaid by remote access software, such as Timbuktu, which permit a user to control a remote desktop. More recently manufacturers of CAD programmes have recognised the need for collaborative working on drawings and are beginning to implement and sell variations of their established products which permit joint working (see for example Goode & Scarponcini, 1997 for a description of the one vendor's response to this market demand).

From Peng's review, we see that more work has focussed on the user interface issues of drawing systems for collaborative work than on issues of information organisation or the provision of graphic primitives and drawing operations (Peng, 1994). Architectural drawing makes significant demands on sophisticated drawing capabilities (Richens, 1990) and it is difficult to produce dense and rich architectural drawings with a system akin to a paint program. As such, multi-user systems still need significant development to provide suitable support for collaborative architectural work.



## 4.2 Multiple modes

While the section above describes four different modes of communicating during a collaborative design process, it is obvious that the tools are employed in a non-exclusionary manner. It is unlikely that a designer would be restricted to only typing or only video to communicate with a collaborator. A combination of tools is needed, and most likely, a different combination at different stages of the design process. Design is dynamic, as are the participants of the design team during a design project. At different stages, as different activities are undertaken and different goals attempt to be met, different tools will become appropriate. As Schön notes, "Drawing and talking are parallel ways of designing, and together make up what I will call the *language of designing*." (Schön, 1983, p. 80, emphasis original). Thus, all four of the technologies outline above are technologies of communication, each with their own role.



**Figure 12:** Multiple modes of communication on one screen



### 4.3 Heterogeneity

There are many brands of hardware and software and many more proprietary systems developed by users. Any collaborative design project must at the outset address the question of the extent to which proprietary or specialist systems will be used.

Specialist systems (including proprietary specialist systems) typically afford greater capability in particular functions than that available from standard or generalist systems. This greater functionality must be balanced against the fact that such systems are (by definition) not broadly used and several participants in the collaborative venture are likely not to have access to the systems.

Most CSCD environments have to be established as a heterogeneous and catholic environment, that is, one which is inclusive and able to handle a variety of different hardware platforms as well as software systems. Users at each node will probably have their favourite (or only) drawing systems which may be different from that at another node. Output from each must be accessible by others. We must also assume that the participants will change over time — few significant interactions have stable populations over the length of the collaboration. Danahy & Hoinkes (1995) describe a typical collaborative environment as consisting of a range of "data types and computational tools...Virtual Reality, Animation, sound, hyperlinks, collaborative-work via Internet, image processing, text, digital library tools, database, interactive exhibitions, customizable interfaces, user history tracking, scripting language and 'C' library support." (1995, p. 647).

CSCD environments must therefore be catholic, generous in their acceptance of technologies and flexible in their implementations. They must support "the fluent meshing of individual work and cooperative work" (Schmidt & Rodden, 1996, p. 166). For such dynamic and temporal interactions, it is unlikely a computing environment can be dictated and sustained. This point is made by Rutherford (1995) although his solution requires a specific platform to handle this transience. It is possible instead, although perhaps not so elegant, to handle the dynamic nature of the system elements by applying commercial standards for data transfer.

One strategy is to build integrated software (and perhaps hardware) systems to support a particular type of interaction (Murakami, et al., 1997; Kalay, 1997; Fruchter, et al., 1996). This is the result predicted by Dennis, et al., 1988 (1988), that the distinct types of CSCW systems will blur and integrate into a single class of IT support for all electronic meetings. While the development of such systems is very useful for research purposes and in the application for specific projects such as a teaching studio, their use in industry is limited. These systems will face the problem that not all participants can or wish to use a specific system for a specific project. Architectural practices typically are under contract for many projects at one time. Training staff in the application of a particular software only for use in one project is disruptive and often infeasible.

It is more likely that collaborative systems will be constructed from discrete components, each with its own functionality. In order to support the exchange of



information, however, each component will need to subscribe to "the semantics of the domain of the cooperating ensemble." (Schmidt & Rodden, 1996, p. 167).

As each technology becomes available for commercial use it goes through a typical evolution in functionality. At the early stages of these technologies, flexibility implies that a lower level of functionality is accepted or extra efforts will have to be made in translating data between systems. Most systems composed of discrete components have problems initially with the interface between components. Data does not transfer smoothly between applications which do not support the same functionality; commands may be constructed differently or features not supported. Often the assembled system is reduced to a lowest common denominator, a strategy which removes the attractiveness of using these tools completely.

As the systems mature, we find that collaboration and data exchange is increasingly accommodated by vendors and systems are either able to read the predominant file formats (e.g. most CAD system can read and write AutoCAD's DWG format) or can handle translations automatically (e.g. word-processing programmes can now quickly translate back and forth between Microsoft Word and WordPerfect). Much as we may dislike monopolisation of technology, it is one way to implement collaboration. The other strategy is to reach industry standards for not only the transfer of data but also the behaviour of systems. This larger goal has been one that the computer industry and its users have pursued since early days but one that continues to elude us all.

## 4.4 Data sharing

Data may be shared as they are created or after they have been created and saved, the saved version then being shared. The technology in these two situations is somewhat different and will be addressed separately.

Data to support collaborative work can be stored in three modes: centrally in a single data location; distributed among the users or other locations; or replicated locally at each workstation. The first model is that common in traditional computer system architectures, with the data residing in a single data server. Distributed data is the model on which the World Wide Web (WWW) is based, with each data file assigned a universal resource locator (URL) and browser servers tracking the connections necessary to put a user in contact with the data file. A common low-end strategy for users who wish to engage no overhead in file management, such as a pair of people working casually on a project, is to replicate the data.

Each of these modes of data sharing carries its costs and benefits. Costs come in the forms of overheads on action (such as learning file naming protocols or converting to shared data formats) or equipment (such as dedicated servers for data storage or resource locators). As the volume of data to be managed grows the solution changes. What is low overhead and low cost for low volumes of data can turn into a high overhead and high cost when used for large volumes of data.

#### 4.4.1 Sharing files

Data can be shared in two ways — as discrete packages of data called upon by a user when needed and accessed through individual applications or through a shared application.

The simpler case is the former, that of sharing saved data files. These files must be able to be transmitted to other participants for their viewing and use. This means the other participants must have the same tools (for example, in the case of a CAD system, the same software) or the image has to be saved and transmitted in a common format, using files with filename extensions such as .dxf for a CAD file, .jpg for an image file or something similar. These files then need to be placed in locations which can be accessed by other participants.

Collaborative work is carried out in a network with nodes, both in the normal computer sense and also in the sense that Latour uses it, as explored in Section 2.5.1. Data for collaborative work at each node have to be identified and the files shared using network file sharing technology or by placing the files in a commonly accessible location. If there are only two participants, file sharing may be handled by simple private means. As projects grow in complexity or as project teams grow in size, the problem becomes geometrically more difficult. Simply placing project files among other data is inadequate. Separating working files from completed and published work is a problem, a problem first described by Wojtowicz, et al. (1992) as akin to 'digital correspondence'. The rudimentary solution proposed and subsequently used in several VDS implementations is to



post publicly accessible files to a central location, called in their paper a 'Pin-up Library'. In a typical implementation of this pin-up facility, files are created by users at the nodes and transferred (for example by ftp) to a single location at which all others can search for information. An application of this idea is expounded in Wojtowicz, et al. (1993).

If web technology is used for viewing and access, the process is easier. Files can then be published in normal web protocols for access by other users. A typical implementation is described by a commercial vendor, Bentley Systems, of their Microstation-based system:

"ModelServer Publisher is a server-based "publisher" of engineering documents. It allows MicroStation design files (.dgn) and other files, such as AutoCAD drawing files (.dwg), to be dynamically viewed and queried across a corporate intranet or the Internet. The published data is viewed using popular Web browsers such as Netscape Navigator™ or Microsoft Internet Explorer. Unlike static publishing solutions, ModelServer Publisher dynamically publishes the current version of the requested document in a user-selectable format without requiring manual pre-publishing of the document by an administrator. ModelServer Publisher's scalable architecture allows multiple documents to be published simultaneously to single or multiple users at any location." (Bentley Systems, 1998)

Making data accessible is not as simple as just publishing it on the WWW, however. The Web makes finding and accessing data very easy. Once accessed, however, it might be changed and the new version then saved, possibly not back in the original location. As every designer soon realises, a common problem in design projects is the proliferation of data and the management of the large number of file. Thus, the version control of data and the location of current files is a significant problem. If each participant manages their own files, locating files during a project can be difficult, if not impossible.

A simplistic system can be used to solve the problem of locating files but does nothing to help the users track new information, identify what is in the files or manage multiplying complexity as permutations of design proliferate. In Wojtowicz, et al. (1993) the team tries to prevent problems by establishing two 'rules' of operation before starting:

"The use of a consistent file naming procedure (for example the file name "parti.o7\_jw" stood for: the image name, "parti;" revision, "07;" last edited by "jw.")

When a new design file was posted on the Digital Pinup Board, a brief description of it was always issued via e-mail to all."  
(Wojtowicz, et al., 1993, p. 111)

These solutions are typical of ad hoc working practices found in small teams pragmatically solving a problem for the immediate moment. The simplicity of this method saw it introduced early on as the first VDS were implemented (for example, Wojtowicz, et al., 1992) and still used even when other technologies are available, for example, Lee, et al, (1997). When implemented for large teams, dynamic teams with changing members or protracted project times, however, the methods need to be a little more sophisticated. For such settings, more extensive and formal systems are needed to assist in managing the data.

More complete control of the data files can be achieved by employing a file management application which tracks file locations, access and changes. File management tools were initially developed to support computer programming teams which had to manage file versions carefully as they developed, maintained and extended software systems. The function of these tools is therefore much like

a library, combining the roles of catalogue, acquisitions desk, borrowing desk and librarian.

File management systems can be easily used to manage any file type, be it software, text or pictures. Savage (1996), for example, describes the use of a document management system in job site communication. One of the problems of these tools is the user cannot see the file contents without going through the sometimes laborious process of accessing a file, checking it out of the library and then opening it in the application. Specialised file management tools later came to be developed to handle particular file types, allowing the user to view the contents of the files before checking them out. There are now a number of commercially available tools to help manage CAD files in which users can preview files to look for particular drawings, confirm if anyone else is currently working on the file, check out files for editing and record notes on changes made when checking the files back in. There are as yet no multi-purpose file management systems which can perform the same functions on a wide range of file types.

Commercial vendors are devoting substantial effort to the development of collaborative tools and recognising that co-ordination of data is a key element. Some packages have reached the market, such as Bentley Systems' *Modelserver Continuum* described in Goode & Scarponcini (1997). In order to provide compatibility with the data already created by existing users, new software are typically extensions of existing systems with only a small subset of the data management and co-ordination addressed.



#### 4.4.2 Shared understanding

If files are posted and shared, users then face potential problems should the elements within the source files be changed. Maintaining co-ordination of data among the many participants is therefore more than simply ensuring that the most recent data file is in use. With large numbers of files available in a typical project, the users have to co-ordinate at the level of components. Different participants will need to interpret components in different ways. For example, a structural engineer will represent a structural system in a manner different than an architect. For example, they will need to differentiate between load-bearing and non-load-bearing walls where the architect will care more about the thickness of the wall. Thus it is important to keep track of information and changes at the component level. Database systems can be developed to support these interpretations of common data (Brown, et al., 1995; Fruchter, 1996; Jeng & Eastman, 1998).

Khedro (1995) describes a system to overcome the problems of co-ordination between team members through the use of notifications. As each team member launches an application which draws upon data, the system registers their interest in that data set. As other team members carry out their work and change elements of that data set, notifications are sent among those working to the effect that changes have occurred. Explanations and rationale for changes can be communicated as well.

A similar approach is assumed in the Interdisciplinary Communication Medium (ICM) computing environment implemented at Stanford (Fruchter, et al., 1996;

Fruchter, 1996). This environment consists of a shared graphic model for design and communication, a semantic model to capture design intent and a change notification mechanism to note changes in the design. The system co-ordinates semantic validity between the components of the design by employing a model of interpret-critique-explain-change notification to support the collaborative work.

While semantics are important to track, the more important aspect is to act on semantic information when the model becomes semantically incoherent. This can happen when one user changes an aspect of the model which violates the semantic properties or rules of another user. Collaborative systems tracking semantics need therefore to provide a system for notification to inform users of this incoherence. Vervenne, et al. (1995) proposes "annotations" which alert the human user. Fruchter, et al. (1996) call these "explanations". Khedro (1995) Fruchter (1996) call them change notifications, a more useful and meaningful term since it implies an active notification of other modules of the system.

Even if you share the same profession and concerns of another team member, it is easy to lose track not only of who is 'present' and participating but also to lose track of the meaning of what is being said or drawn. Not every intent or meaning will be encoded into the system since some meanings are emergent and arise during a design process, not only in the drawings but in words and meanings (Lawson & Loke, 1997). While misunderstanding can have fortuitous outcomes in virtual design studios (Cheng, et al., 1994), it is probably more important that the participants understand the content of the exchanges as they are occurring. There

are mechanisms for developing this shared understanding, or shared cognition, in conversational experiences (Schegloff, 1991) but such systems need to be developed for CSCD.

As the conversations become asynchronous and multiple in their media, as an architectural design 'conversation' does, the problems of shared understanding become more acute. Design projects typically endure for extended periods (often years) and participants change. Saad and Maher (1996) have noted that the problems become acute in collaborative design environments. With no shared location, the corporate memory of the project is easily dissipated. Thus Saad & Maher argue that the sharing of data itself is inadequate but must be supported by a shared understanding of the artefact. Thus, a record of a design must include graphical and semantic objects that can be abstracted and aggregated.

What kinds of semantic data might be tracked? Portillo & Dohr (1994) identify five categories of semantic data to track in industrial design: behavioural (e.g. user action needs); compositional (aesthetics); symbolic (e.g. image); preferential (e.g. market trends); pragmatic (e.g. cost). It would appear that this list needs to be supplemented for architectural design, at least, by extending behavioural to include the behaviours of the building and its components. As Khedro (1995) illustrates, computer tools can be developed to support the retention of semantics and intent over the course of a collaboration.



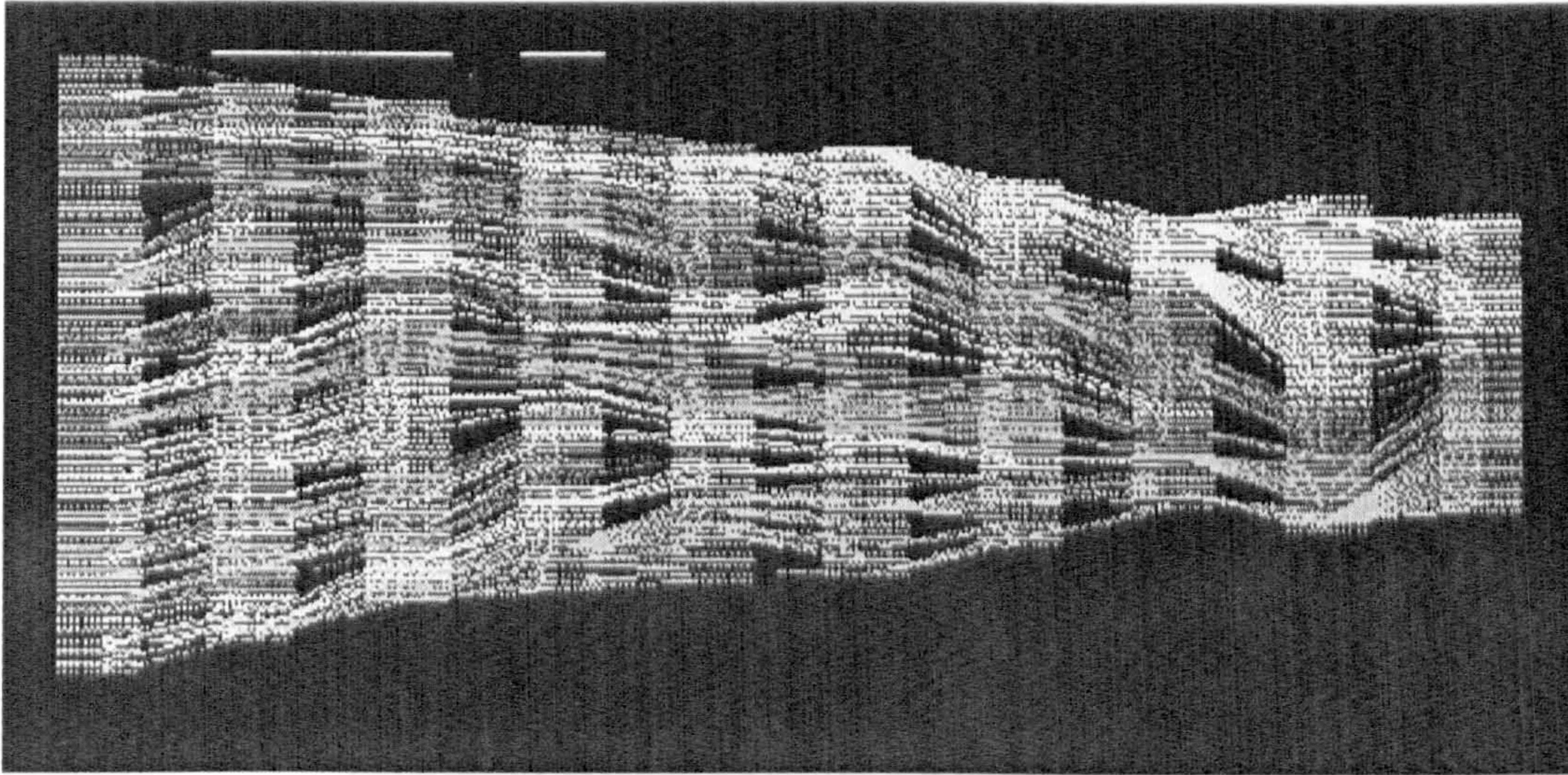
### 4.4.3 Tracing heritage of ideas

In a dispersed collaborative effort, designers may wish to track the history of designs overtime both to ensure that design intent is implemented and to trace authorship. As data are used, changed and engaged, it becomes richer. McCullough & Hoinkes (1995) examine the nature of data in a collaborative urban planning environment and suggest some of the complexities which are posed by managing evolving data within the context of a VDS. The paper does not get into specifics of implementation but highlights usefully the importance of the need for maintaining the richness of the data while offering a simplicity of access.

Design intent can be found in design programmes, user interviews as well as in the history of the work, such as in annotations of drawings as they are reviewed during design. A formal computer system for doing this specifically to support collaboration between designers is explored in Vervenne, et al. (1995) with agents developed to process "annotations" (comments) and track implications as designs develop. The system described is incomplete and no evaluation of the usability is reported.

In a teaching context, it is useful to trace the heritage of ideas so that the class can discuss how ideas evolve and grasp the idea of design evolutions. A different approach to tracking design heritage in a teaching context is described in Wenz & Hirschberg (1997) (Figure 13). The authors call this "memetic engineering" as the evolution of ideas (memes) can be tracked and design heritage evaluated.





**Figure 13:** Graphic representation of memetic evolution  
(from Wenz & Hirschberg, 1997)

#### 4.4.4 Data standards

Larger corporations sometimes take the initiative and demand co-ordination occurs through proprietary means. Particular teams in commercial settings have developed highly comprehensive and complex tools for co-ordinating data, for example, the database system described by Abarbanel, et al. (1997) in use by Boeing to distribute and co-ordinate the design documents for the Boeing 777 aircraft.

Ad hoc methods can be inadequate. A project team working with several clients may find themselves forced to work with equally many ad hoc techniques for organising data as each client establishes their own methods. Thus we see efforts such as the promulgation of common CAD layer naming conventions in an effort



led by the American Institute of Architects and supported by a wide range of professions and client groups (*CADD Layer Guidelines*, 1990).

While file naming is sufficient if all users employ the same application software, this is often not the case. Data may come from a number of applications but must be available for use by all team members. This has lead to calls for cross-application data standards. Industry-wide efforts to establish common data platforms have been ongoing for many years and have lead to a variety of data standards being promulgated. Some of these are based on data structures borrowed from dominant vendors (such as DXF from Autodesk), others established by international committees (such as IGES and STEP). Some tools have been developed on these standards to provide integrated databases to support collaborative design (Kim, Liebich, & Maver, 1997).

Not all data can be structured tidily in a database. Design activities often call in stored ideas from long in the past or apparently ephemeral to the process. This problem plagues all architects whose offices often resemble warehouses rather than studios — carpet samples, old models, drawings, books, artefacts etc. clutter the work surfaces. In digital form, the same clutter exists but the dictates of digital storage make filing more important. The design of storage systems for digital collaborative design in a long term professional setting needs to address this casual access of ephemera (Harrison & Minneman, 1995).



#### 4.4.5 Interacting on data

If the participants are to interact concurrently on the same file, they will need a common tool for simultaneous use of a file. This can be accomplished by using a shared paint surface such as a Whiteboard in which two or more participants can draw using tools similar to paint programs. Many whiteboard systems permit images (as bit maps) to be pasted in from other programs and some (such as Collage) permit three-dimensional models to be pasted in and manipulated. Whiteboards are commonly used in VDS settings, as noted in Dave (1995), Cheng, et al. (1994) among others.

The limitations of whiteboards are identified in Jabi & Hall (1995), primarily as being the unstructured nature of the data, the semantics of the drawings. Their system SYCODE offers multiple hardware platform support with proprietary software. They have also tried to address the changing nature of data over time, recording in the database versions of designs developed by each participant.

Alternatively, if all participants have the same software and hardware technology, programs can be found (such as Timbuktu) or created to allow multiple users simultaneous access to the same file. An added sophistication of the interaction can be achieved when the participants can interact using a three dimensional model.

Morozumi, et al. (1995) describes the use of two windows on each screen, a Personal Window (PW) and a Common Window (CW). Only the workstation user

sees work in the PW, work in the CW is shared to all participants. The system relies on the workstation user to make information public for the duration of the collaborative session and does not allow remote accessing of saved files.

## 4.5 Participant communication

Communication between participants must be considered in three facets — modes, synchronicity and privacy. Each of these are addressed here. Before addressing these individually, it is useful to remind ourselves that communication in collaboration does not imply a positive agreement in every communication. As Easterbrook (1996, pp. 98-104) reminds us, conflict stems from a variety of sources.

- ontological drift (differences in interpretation)
- learning, forgetting, belief revision (changes of understanding over time)
- assumption and uncertainty
- boundary objects (shared artefacts used for different purposes)

Breakdown occurs when one person models things differently from another. It can play a "vital role in group interaction, in revealing the limitations of shared understanding and revealing hidden conflicts" (1996, pp. 98-106) and can be used explicitly, either as team members play devil's advocate, agent provocateur or to exert power. Teams can develop harmonising mechanisms assist in developing shared understandings, either by explicit dialogue rules or by developing other techniques such as gesture, facial expression, eye contact in a face-to-face context.

Techniques can be developed explicitly in collocated settings, such as partnering meetings (Allbriton & Smith, 1996) or in non-collocated settings without visual contact to the same effect (L'Henry-Evans, 1974).

#### **4.5.1 Modes**

Discussions about communication between participants immediately focus on whether the participants can see and hear each other or not. Various technologies can be used to convey video and audio connections. Commercially available tools to support collaborative working (such as Microsoft NetMeeting) have video and audio support built in. Typically these connections have low throughput or are constrained by the network bandwidth connected to the computer. As noted in Bly, et al. (1993, p. 44), even high bandwidth connections are plagued with problems or feedback, delays and degeneration of audio fidelity which lead to problems and inadequacy in communication.

Video communication requires even higher bandwidth capacity. As bandwidth falls, the image is less frequently updated. Updating at 24 frames per second conveys near real-time images. As soon as refresh rates drop below real time users can become disconcerted and distracted by the video. In low bandwidth situations, we often encounter refresh rates of less than once per second.

Video connections must be large enough in order to convey information in order to be useful. There is no research yet to identify the size or resolution of a video image necessary to support communication in a collaborative setting. Our



experience in VDS settings is that the small images provided by NetMeeting or other desktop video camera systems are insufficient in size or resolution to convey much information other than presence.

### **4.5.2 Synchronicity**

Communication between participants can be synchronous or asynchronous. It is typically useful to have both forms available. At times, users will be online at the same time and wish to work together. At others, time zones will make it inevitable that users are communicating to others who are offline.

#### **4.5.2.1 Asynchronous**

Asynchronous text communication can be accomplished using e-mail. Asynchronous video and audio can be achieved with video mail — the attachment of video or audio files to mail messages which can be retrieved and played at the convenience of the recipient, saved and replayed as needed.

E-mail is typically a one-to-one or one-to-many system which renders all communications between members private. Once the e-mail is received, it is stored or deleted according to the recipient's desires. In a team-based project, it is useful to have communications shared among team members and recorded for later reference. The importance of project communication is an essential component of project management (see Chappell & Willis, 1992, p. 261 for example). Since e-mail is normally directly from sender to recipient (or multiple recipients), it leaves no public trace. Project management becomes very difficult

without this public record which can be consulted by different team members. E-mail is therefore a poor tool for project communication.

To overcome this problem, some VDS projects have used bulletin board systems to which all messages are posted and threads formed to track communications. Cheng (1998) describes one such VDS application using Hypernews to which all e-mails were posted and organised in threads by team and topic. In this system, the system appears to the sender as a typical e-mail system — screens requesting a recipient's name, a subject header and a message. The message is then sent to a web page available to all participants in the design exercise and filed under the recipient's name. Communications are cumulatively recorded, new messages appearing indented under headings for each thread or with a new heading for a new thread. Thus, all exchanges were available to be seen by all (although the volume of exchanges made it unlikely anyone person would read all exchanges) and the history of the project could be reviewed. Lee, et al. (1997) describes a hybrid implementation which uses a bulletin board for issues of common interest only, while e-mails communicated privately and directly between team members.

#### **4.5.2.2 Synchronous**

Synchronous text communication can be accomplished by Chat (for which there is a multitude of programs). Chat communication is a typed exchange in which participants use the keyboard and type their comments in a window on screen. The window is either divided into a number of panes, one for each participant, or comments are flagged by colour or label to indicate which participant has typed

them. Synchronous communication can be implemented using tools such as Microsoft NetMeeting or a MOO.

Chat exchanges typically are transient — the participants type back and forth and when the typing window is full the text starts to scroll. Some (such as Microsoft's NetMeeting) record the exchanges and transcripts can be archived for use later.

### **4.5.3 Privacy**

Communication can be private or publicly accessible. Private communications are those accessible only to sender and recipient. Public communications are those accessible by others in the project team or class. Degrees of privacy can be achieved by the choice of communication system and by password protection.

## **4.6 Reviews**

Design reviews pose a particular and distinct problem for the implementation of Virtual Design Studios. Typically, reviews of the technology of VDS do not distinguish between the design and review processes. Saad & Maher (1995), for example, explore the technical implications and implications for technology for collaborative design. In their paper, they distinguish between closed and open systems; between the possibility to multiplex or co-ordinate; between singular solutions or environments composed of multiple packages; separate versus integrated video capability; and common versus multiple representations. They then distinguish the role of the workspace as having four roles: information



sharing; communication media; process management; and exploration space. No discussion of the review process is presented nor of the technology to support reviews other than that which may occur between designers during the design process itself.

The review process is an integral and essential part of the design process, whether in educational settings (Anthony, 1991) or professional (Bozdogan, 1989, p. 147; Coxe, 1989, p. 94). The process can be formal, such as a final presentation at the conclusion of a project or semester, or it can be informal, such as an interim pinup to review ongoing progress or work on the desk. For example, Charles Gwathmey, partner in Gwathmey Seigel & Associates New York, quoted in Franklin (1989, p. 38), notes the continuous reviews at the desks and the scheduled pin-ups of projects on Fridays. At times it can be intense and the participants very involved (for example, David Packard's involvement in the Monterey Aquarium described by Cuff (1991, pp. 224-225) while at others a more dispassionate environment pervades. In view of the importance of reviews, it is curious to note that standard texts on professional practice such as Thompson (1990) and Chappell & Willis (1992) fail to discuss the need for design reviews even though professionals consider it essential.

Our current model of juries is one in which temporally and geographically situated — they take place in a particular location and at a particular moment. Designers (students or team members) stand to present their work, jurors (experts in the field, teachers, passers by) are free to comment on the work, designers may

respond and the group moves to the next problem. This particular form of design review has a brief history. The Beaux Arts tradition was of closed juries — student work was submitted by a particular time and evaluation was conducted behind locked doors with only the evaluation panel present. The change from closed to open is recent. As noted by Anthony:

"the exact dates for this radical transformation have never been documented, but conversations with designers of different ages indicate the process was gradual. The major change appears to have occurred during the late 1940s and 1950s... The reason for this dramatic shift are not crystal clear." (Anthony, 1991, p. 8)

If we wish to support an open design jury in a VDS, we need technology to support the presentation and feedback steps. Shelden, et al. (1995) describe in detail the systems and (in particular) the personnel required to support a design jury implemented to as closely as possible mimic a face-to-face open jury.

More limited versions of design juries can be created using a simply video and audio connection but the limitations of communication render the process cumbersome and unsatisfactory. The bandwidth and technology are substantial and the results less than satisfactory. Face-to-face juries gain much of their benefit for the participants from casual interaction of the participants — as noted in Shelden et al., the technology does not support this well.

The presentation of project information is problematic in virtual reviews, as often noted in descriptions of virtual reviews such as Shelden, et al. (1995) and Cheng (1998). We have well established traditions in face-to-face reviews of materials displayed on vertical surfaces, models arranged on stands and jurors and

presenters moving around the material. All participants are able at any time to glance across to other displayed material, taking their attention away from the item under discussion. Virtual reviews preclude that. The presentation is more scripted, the sequence of presentation for material typically under the control of the presenter. Where bandwidth precludes "pushed" images (rather than the viewers "pulling" the image they want to see, in normal web usage), the viewers at each node can follow instructions to "turn to image x" to maintain synchrony between nodes and hence discussion. Most synchronous virtual reviews to date have been conducted using web browsers as interfaces, with synchronised "pulling" of images on command. Where total synchrony is desired (as in Shelden et al.), the images are transmitted by video link from a central control studio. This reliance on video transmission increases the bandwidth requirements and can reduce the visual quality of the images as they are filmed and retransmitted.

An interesting solution to the problems of co-ordinating the attention of participants during a review process is proposed in Lee, et al. (1997). Here, the designs were translated into VRML and review participants could navigate their way around the 3D project model in both a design and review phases. Their positions within the model were represented by avatars that could assume states of emotion, either happy or angry visages. Additionally, the avatars could gesticulate by waving. Reviewers could then explore the VRML model and encounter other reviewers. The avatars indicated the direction the review was facing and the visage crudely reflecting their perception of the design. A chat window was



implemented below the VRML model to supplement these simple representations and extend the conversation.

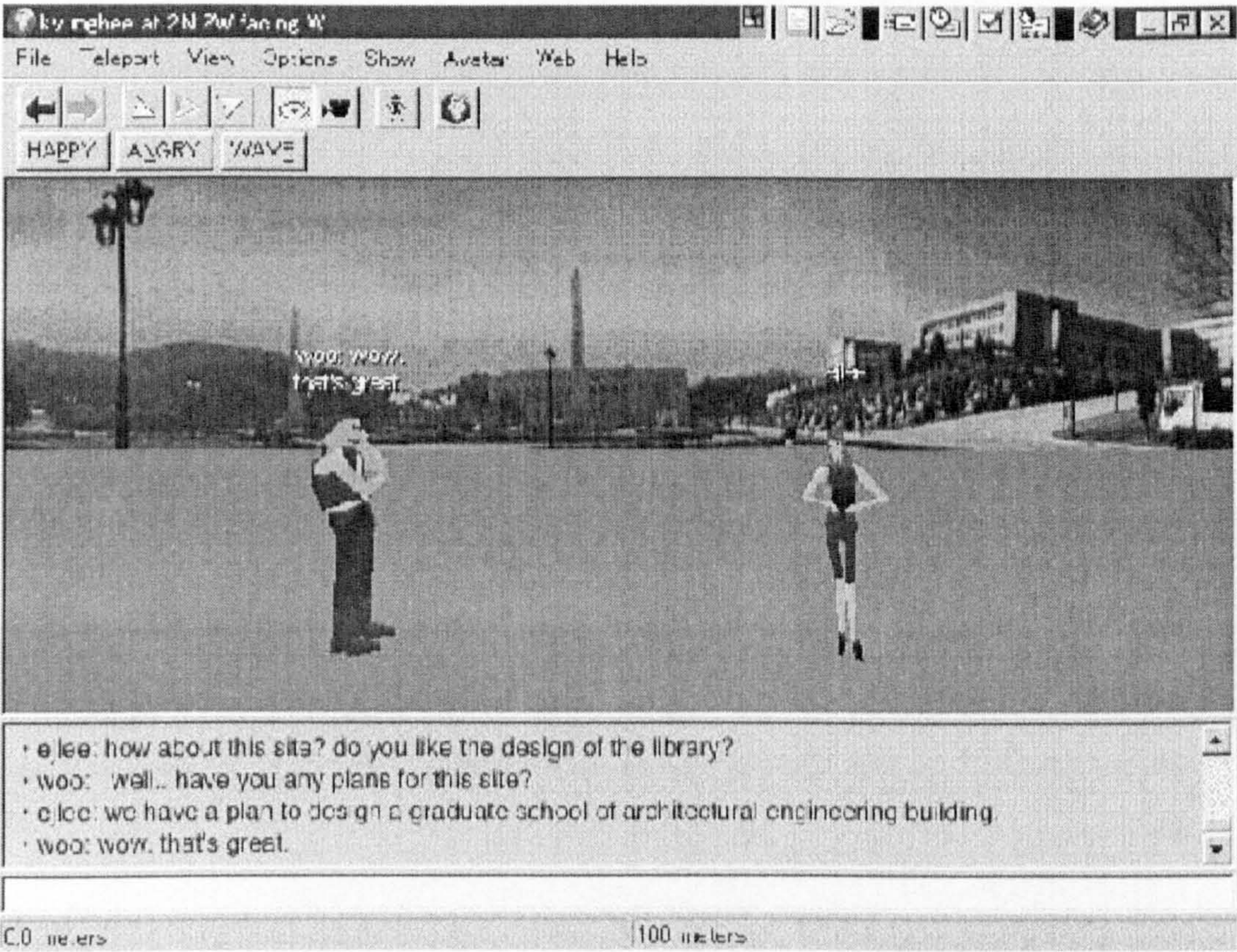


Figure 14: VRML model with avatars (from Lee, et al., 1997)

Alternatives can be considered and some virtual studios have taken advantage of them. It is common now for teaching studios to post all their presentations online and request remote jurors to view the results and send communications back to the design teams by e-mail. Lee, et al. describe one such implementation used in the course of the design project to allow team members to review and comment asynchronously on work carried out at two remote sites.



Closed juries are used in many design competitions today. An anonymous voting system can also be used. Neither of these systems is effective in providing feedback to the designer.

New forms of participation are possible using computer technology. A MOO can be used to permit user interaction, although presentation of images is constrained. In the teaching context, asynchronous viewing of the work online is sometimes tried, with jurors forwarding comments to students by e-mail.

## 4.7 Conclusion

There are a wide variety of technical tools available to support collaborative design. Whatever tools are applied, they need to satisfy at minimum a simple range of capabilities:

- describe a design (by word, line or image);
- communicate the design to other participants;
- permit feedback to come from other participants;
- permit data to be stored and retrieved.

Notice that this list does not included replication of the sensation of 'being there' as a desired goal. From the discussion in the previous chapters (and as demonstrated in the experimental results presented in Chapter 5 below), it can be seen that removing the effects of distance by application of high bandwidth to replicate face-to-face interaction is not a necessary nor suitable goal for CSCD.

While there are problems or delayed feedback and restricted communication associated with being at a distance from a collaborator, these constraints are not necessarily detrimental to the project.

How you go beyond the list of capabilities above depends upon the goal you are trying to achieve. CSCD systems can support a variety of tasks and design phases, each with its distinctly different needs. As Dorst and Dijkhuis (1995) concluded, describing design as a rational activity can be most apt for situations where the problem is clear-cut and the designer can postulate strategies for solving them. Design as reflection-in-action describes the whole design activity but is limited in its usefulness as there are no theoretical underpinnings which permit general conclusions learning to be drawn about the particular design. The authors suggest that latter model is particularly useful for education and design practice, especially in the conceptual stages of design where the path and solution are not clear. From this we could assume that a collaborative design system to support early conceptual design should focus more on communicative systems to support problem solving exchanges while a collaborative system for later work might include discrete design tools. Perhaps in these synchronous situations, video and audio would help the process.

In other phases of design, different support would be needed. As we can conclude from CSCW research into problem solving, collaborative activity benefits from a structure and from social equalisation, including anonymity (Gallupe, et al., 1991; Kiesler & Sproull, 1992). For particular problem solving steps in design, it may be



beneficial then to employ technology to provide structured and anonymous discussion of the problem at hand. Video and audio would in these situations be damaging to the process.

Ideological positions also prejudice discussions — those who subscribe to the position of situated actions (Suchman, 1987) *a priori* insist that multiple wide-band communication modes and channels are required (Schmidt & Rodden, 1996). This belief that social processes play a critical role is often unquestioned, to the extent that some CSCW research, e.g. Fitzpatrick, Kaplan & Mansfield (1996), *assumes* that collaborative activities, especially remote collaboration, can only be understood in terms of the social/physical context. By assuming that situated actions, for example, are “givens” (Fitzpatrick, et al., 1996, p. 334), the studies have reinforced the assumption that replication of physical spaces are necessary for virtual spaces to succeed. This automatically leads to the assumption that video and audio communication at a high bandwidth are *a priori* tools for successful collaborative distal design. Hollan and Stornetta have highlighted the difficulties of this assumption and the failures of attempting such replication (Hollan & Stornetta, 1993).

Other users find themselves constrained by technological limitations; low bandwidth is a common problem. Few sites have adequate bandwidth to support the 12 channels of communication required for a “truly interactive group communication” (Shelden, et al., 1995, p. 8), reporting a conclusion from Bly, et al., 1993 which I cannot find in reviewing their work).

Each of these capabilities can be interpreted in many ways, either by addressing issues of synchrony or capacity. As Easterbrook, et al. (1993) have observed in reviewing the work at Xerox PARC:

Effective communication matters more than communication bandwidth. While video mediation does introduce significantly better awareness of the status and disposition of one's partners in a conversation, the increase in communication power does not seem to be commensurate with the increase in telecommunications bandwidth required over an audio connection. (Easterbrook, et al., 1993, p. 56)

Perhaps the emphasis should be on process understanding rather than technological solutions. It is possible to implement CSCD using low bandwidth settings and tools. Effective communication can depend upon training and process as much as technology. Users have to adapt their means of communication to the tools available, be they pencils, paints or digital media. Kurland & Barber (1996) have noted that collaborators in the digital realm do learn new means of effective communication as they assimilate the tools.

Depending upon the desired outcome, the tools will need to change. If the goal is satisfaction in the experience of communicating at a phase of the project that requires negotiation, then video support may be important. In a phase where technical problems are being solved or design solutions sought, the outcome of the experience will depend more upon the knowledge and expertise of the participants than it will on the technology employed. It is more important to have a team of well-trained architects and consultants participating than investing large sums of money in high bandwidth communication. It is also important to define appropriate goals for the interaction. Project-focussed goals which are design

related will be achievable using these lower bandwidth technologies. If the goal is to collocate two teams, then it is unlikely that the low bandwidth system will suffice but there is little evidence that high bandwidth systems will achieve this goal either. If collocation is important and essential for some reason beyond collaboration, it is probably necessary to physically do so.

One may take these findings to suggest that the particular configuration of tools is irrelevant. This is not the case, although well-trained professionals are able to work well in the most adverse situations. Some configurations will support particular goals better than others. Practices have for several years now worked very effectively with faxes and telephones, two technologies which share a communication mechanism but do not permit any transfer of data. CSCD configurations can easily better this environment.

Almost all CSCD configurations today will be ad hoc compositions of a variety of applications. Reliance on any one tool will probably not suffice. The primary principle which will underlies CSCD implementations will be the flexibility and inclusiveness of their structure, their catholicity as it has been termed here. The natures of architectural design and architectural practice demand such flexibility.



## **5 An Experiment in Design Collaboration**

This chapter describes the results of a study evaluating the effects of computer mediation on collaboratively solving architectural design problems.

In reviewing the work of CSCD in Chapter 3, we saw that the efforts have been made in supporting communication are grounded in the assumption that collaboration is best supported with video and audio connections rather than text links. This chapter presents a study which examines this assumption in detail and suggests that CSCD may well be better supported in a framework which not grounded in the face-to-face analogy. The chapter therefore is a detailed examination of one of the issues raised in Chapter 2 and 3.

The study was carried out as a joint project between this author (Thomas Kvan) and colleagues in the Cognitive Science Centre at the University of Hong Kong, namely Alonso Vera, assisted by Robert West and Simon Lai. Joint papers have been published reporting on this research at different stages of its execution (Kvan, West & Vera, 1997; Kvan, et al., 1997; Vera, Kvan, West & Lai, 1998; Kvan, West & Vera, 1998).

This chapter describes the two conditions of the experiment, outlines the methods used, presents the data and concludes with a discussion about the implications of these for the design of computer systems for collaboration.

## 5.1 The experiment

The experiment was carried out to investigate the effect of bandwidth on design collaboration. Two different conditions are presented, one in which the two participants of each subject pair are both students in the Department of Architecture, one a landscape architecture student, the other an architecture student. In this condition, the problem set is a landscape problem of the type both architects and landscape students are trained to handle.

In the second condition, the problem is the design of a school playground and the collaborators have different, but complementary, domains of knowledge with the design problem existing at the intersection of their domains (the design of a kindergarten playground): one is a student of architecture while the other is a

student in the Master of Education programme in psychology who has some training in the theories of play. Eleven pairs of subjects participated in the first condition and eight pairs of collaborators participated in the second condition.

The two studies were used to explore the question whether the knowledge of the participants affected the demands on communication. In the first condition both participants have the same domains of knowledge pertaining to the design process; in the second the domains of knowledge are different with one participant knowing nothing about design while the other knows nothing about play theory.

Detailed descriptions of the design problems and experimental conditions are presented below. Protocols were collected and transcribed before encoding. Two coding models were used, one based on the cognitive model described in Chapter 2 and a second model to identify the type of design communication exchanged. Both of these are also described below.

## **5.2 Condition 1: Shared domains of knowledge**

The subjects were twenty two graduate students from the University of Hong Kong. Fourteen were peers from the Department of Architecture and eight were peers from the Department of Landscape Architecture. The students had at minimum two years of professional degree training in their fields, enabling us to classify them as 'expert' in the design domain for this problem (Verstijnen, et al., 1998, p. 535).



### 5.2.1 The Task

The participants were presented with site plans (see Figure 15) and a written problem definition as follows.

**Objectives:** To resolve site access problems using basic rules of site design

*You are to work as a pair together to design a rest area and car parking with pedestrian access within a sloped site as described in the attached site plan. The site consists of an evenly sloping site with a 13 meter difference in height from a hospital entrance at the top to a bus stop at the bottom. A car park for six cars is to be placed on the site half way up the slope with access from Middle Road.*

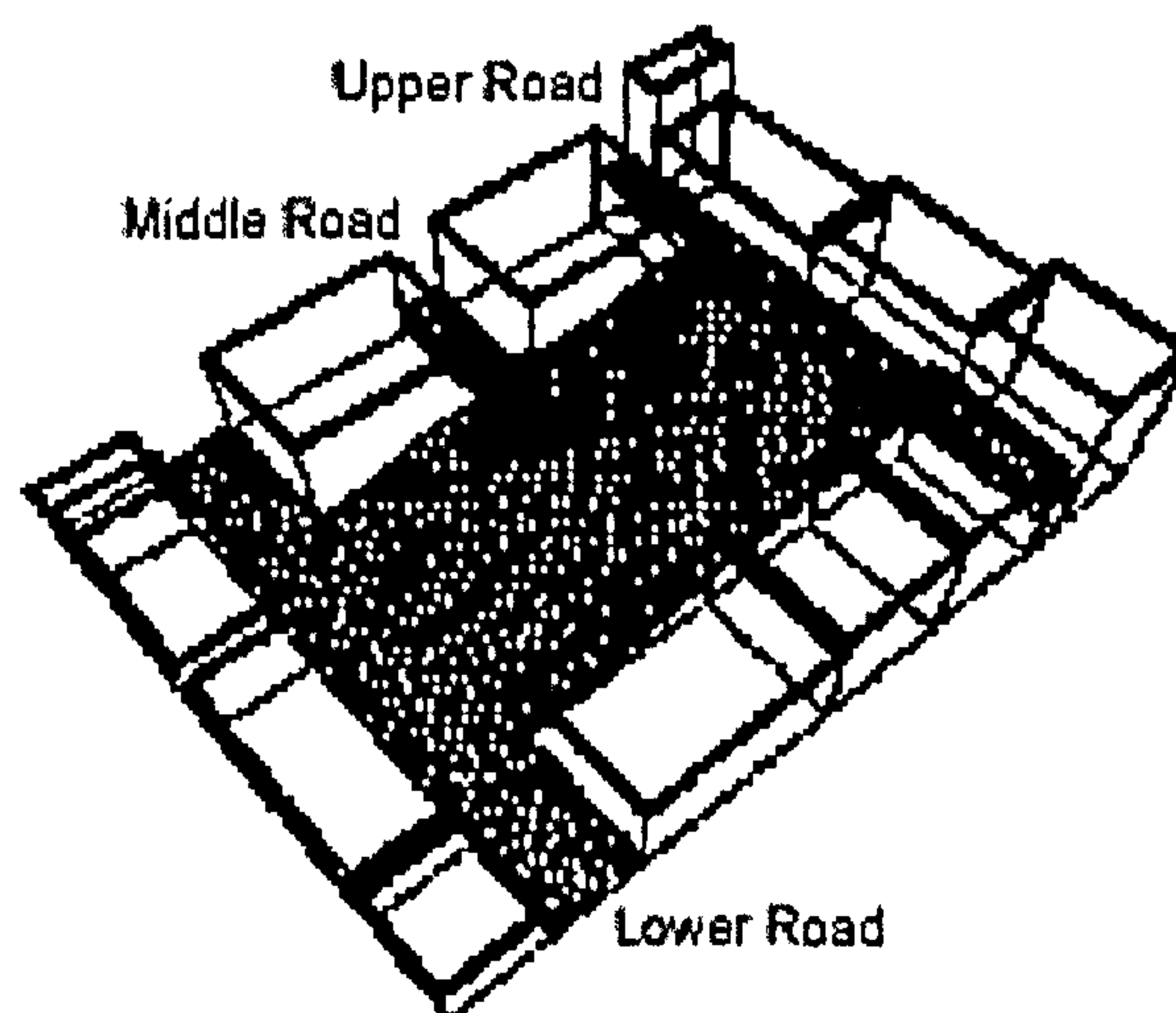


Figure 15: Design site used in Condition 1

*The design challenge is to provide*

- 1. access from the bus stop to the hospital*
- 2. access from the car park to the bus stop and the hospital*
- 3. a seating area for up to six people and perhaps a play ground for children at an appropriate point on the site*
- 4. routes which are not too steep*
- 5. appropriate vegetation and landscaping to complete the design concept*
- 6. a sense of arrival at each site access point*

*While achieving these goals, you should try to:*

- minimise cut and fill*

- *minimise contour changes*
- *drain the site appropriately*

### ***Useful information***

*During this exercise, use the following guidelines:*

*Maximum angles for slopes should be:*

<i>1:2</i>	<i>50%</i>	<i>slopes for unmowed landscapes</i>
<i>1:3</i>	<i>33%</i>	<i>for mowed grass surfaces</i>
<i>1:6.7</i>	<i>15%</i>	<i>maximum slope for cars</i>
<i>1:12</i>	<i>8.33%</i>	<i>handicap access ramps</i>
<i>1:20</i>	<i>5%</i>	<i>parking area surface (drain water off parking area)</i>
<i>1:1.5</i>	<i>66%</i>	<i>stair</i>

*Minimum angles for slopes should be:*

<i>1:67</i>	<i>1.5%</i>	<i>minimum slope for drainage</i>
<i>1:3</i>	<i>33%</i>	<i>minimum slope for stair</i>

## **5.3 Condition 2: different domains of knowledge**

The second condition brings collaborators together who have orthogonal domains of knowledge in regard to a particular problem posed. The participants were drawn from two courses at the University of Hong Kong. One group was recruited from the Master of Education programme course in educational psychology. These students are all practising teachers who are studying to upgrade their basic teaching qualifications. Their collaborators in this problem were students in the Masters of Architecture course in design computing, all of whom have some experience working in design offices as well as holding initial degrees in architecture. Some of these latter students were also participants in Condition 1.

### 5.3.1 The Task

The problem set in Condition 2 involved the design of a playground on the roof of a multi-story building, a not untypical situation in Hong Kong where terra-firma is in short supply. The participants were presented with the following problem definition:

*You have been asked to collaborate in the design of a playground for a kindergarten of 50 pupils 4 –5 years old. The playground is on a rooftop above the school. Available area is 178 m<sup>2</sup> and can be assumed to be safely surrounded by fence or wall. You should concern yourself with the choice and placement of elements within the roof area.*

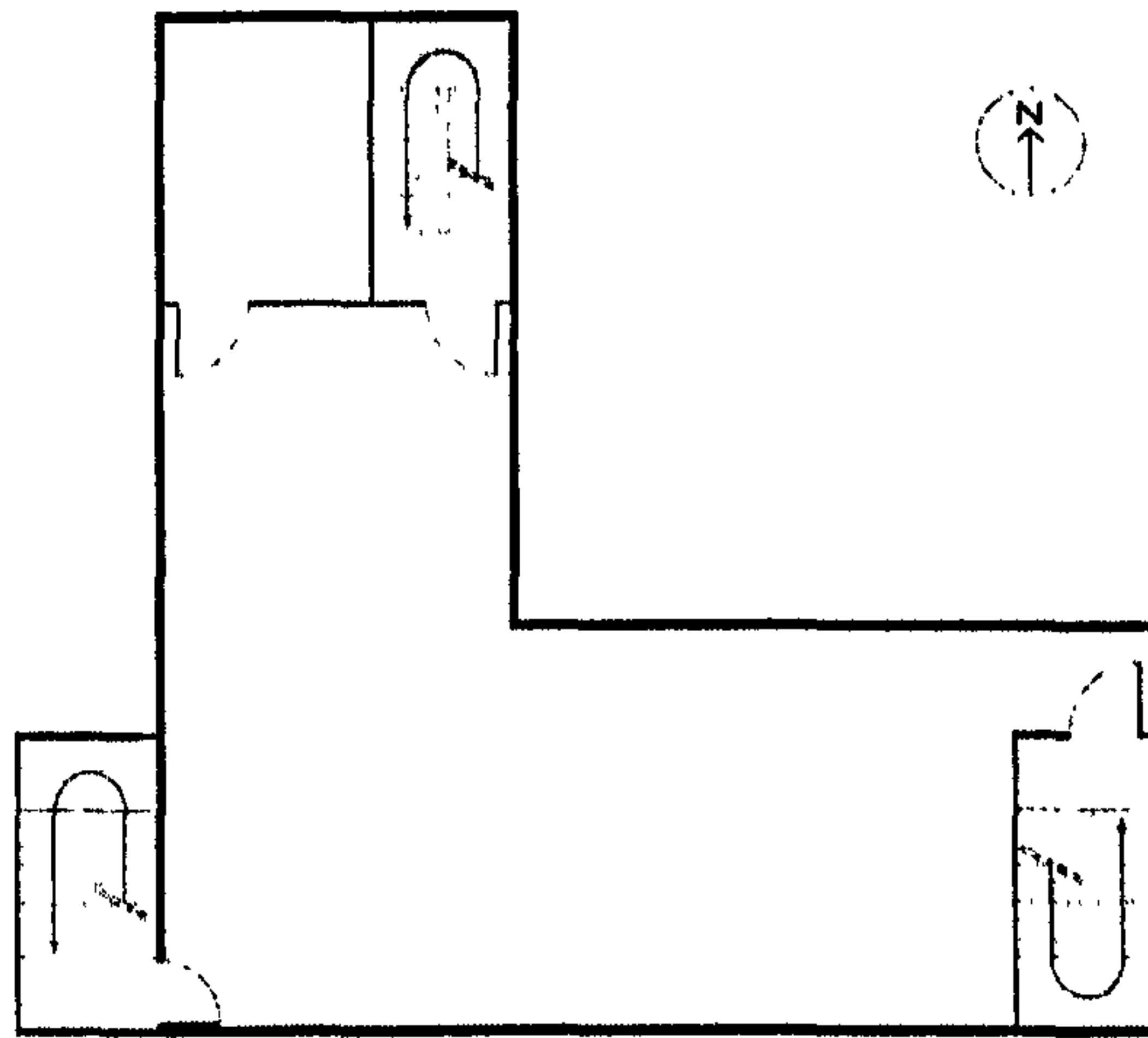
*The rooftop has three access stairs which connect to the kindergarten. You have been asked to close two of these to restrict access by only one stair. The others will be fitted with fire bolts to permit use in case of emergency only.*

*The playground design should respond to the educational and social needs of children as well as safety and enjoyment. Within the time allotted for your collaboration, devise an idea for the playground and create a drawn record of the idea. Use any symbols you wish to represent objects in the plan but make sure it is legible and can be understood.*

*Note for Architectural students: Working with the educational advisor, you need to consider circulation; access; sense of place; lines of sight; and shade. You should use play equipment; shading devices; and seating elements to create a play area to meet the needs of the educational advisor. You can ignore any loading conditions and assume any services you require are available.*

*Note for Educational students: Working with your architectural collaborator, consider issues of safety and developmental needs for play. Consider issues of exploratory play that uses active, sensory, constructive and social components. Allow for imagination and creativity in play.*





**Figure 16:** Design site used in Condition 2

## 5.4 Method

Two adjoining rooms were each equipped with Pentium computers. Both computers were equipped for video conferencing and were connected by a local area network. For software we used Microsoft NetMeeting which supports remote audio and video as well as a shared electronic white board and a chat line. For the audio we used head sets with an integrated microphone so that the subject's hands would be free. For the video we used Connectix's Color QuickCam for Windows. The video camera was placed on top of a 17 inch monitor facing the user's face. The image showed the workstation user from neck upwards. The size of the image was set at 3 inch square. The NetMeeting window was set to fill the remainder of the screen, with the chat line (where it was used) filling the bottom two inches of the screen. The users could resize windows as they wished.

Even with the computers directly connected we found that the audio and video were of poor quality since NetMeeting passes the communications through a central server. To remedy this we used a telephone line for the audio and a direct feed for the video (i.e. the video cameras sat on one computer but were actually connected to the computer in the other room). All connections passed through the wall so that, with the door between the rooms shut, subjects were cut off from any direct communication. This allowed us to simulate a high band width communication between remote hosts.

Subjects were recruited from three sources. The architecture students in Condition 1 were fourth and fifth year students in an accredited five year architecture degree programme. From a class of 70, 14 were recruited. These 14 were taking a seminar class in computers in architecture to which they had been randomly assigned by the Department of Architecture. The eight Landscape Architecture were in their second year in a two year accredited Master level course. These eight students volunteered (out of a class of 10). Condition 2 was run one year after Condition 1. The architecture subjects in Condition 2 were similarly selected from the pool of architecture students but, being conducted one year later, the subjects were not the same people as in Condition 1. The Educational Psychology students were all practising primary school teachers taking a part time Master's course. Attendance was part of their coursework. In all cases, subjects were asked to indicate times at which they were available and random pairing assignments were made by the experimenters based on mutually available times.

## 5.5 Procedure

In both studies, the procedures followed were the same. There were two conditions, one in which subjects could communicate using audio and video (i.e. they could see and hear each other), and one in which subjects used only a chat-line (i.e. they could send written messages to each other). In both conditions subjects could also use the electronic white board. Subjects were run in pairs; the video conferencing condition had nine pairs and the chat-line condition had ten pairs. Each pair of subjects was instructed in how to operate the conferencing technology and told that they would have one hour to solve a well defined design problem using the shared space of the electronic white board. They were then given the problem and separated into the two rooms. Each room contained an experimenter to directly observe the subject's actions. The sessions were videotaped in each room. A site plan was already present on the electronic white board. After one hour the experiment was stopped.

After all the experiments in one condition had been run, the videotapes were reviewed and the audio portions of the exchanges transcribed for protocol analysis. Chat line conditions generated their own protocols during the chat line exchanges. These were saved at the end of each session and printed later for the session's protocol. Thus for each session a protocol was generated for analysis later. Chat line protocols were on average six pages, single space, 10 point type, on average while transcribed audio protocols were on average twice the length. A total of approximately 180 pages of protocols were coded. A sample protocol is

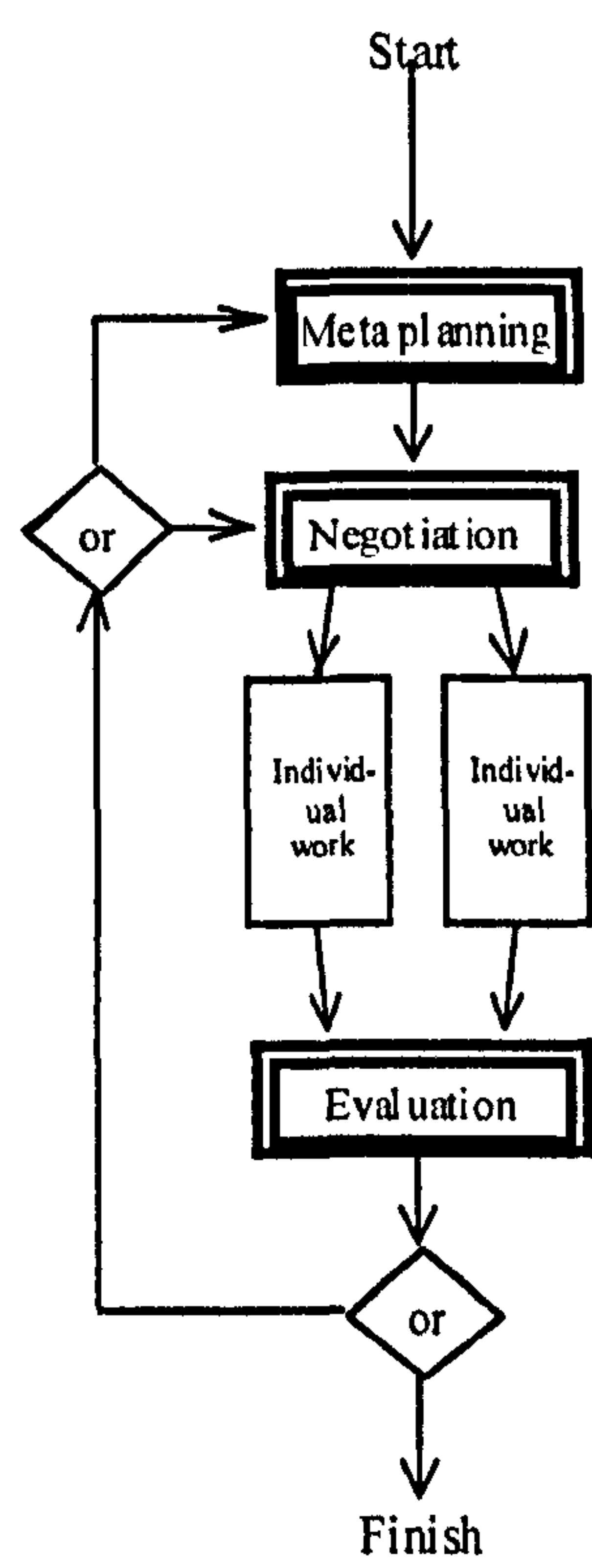


attached in Appendix 2 of this thesis. This author coded all the design content protocols, co-author Vera coded the collaborative process protocols. In addition, the two authors coded two protocols using the other's schema to ensure reliability.

## 5.6 Collaborative Process Model

The experiment starts with the cognitive model of collaboration presented in Chapter 2 (repeated in Figure 17). This model describes the steps by which collaborators may engage a problem, moving from meta-planning through negotiation to evaluation. Note that this model does not attempt to describe the architectural content of a collaborative experience, only the collaborative process.

We note again that collaboration will involve personality, emotion, culture, and many other social and psychological factors in addition to the problem-solving process. We suggest that these do not play an important role in shaping (or reshaping) the combined expert knowledge or the measurable product of the collaboration. As in Olson & Olson (1991), our focus is on the cognitive aspects of collaboration. We argue that this is shaped primarily by the skills and expertise of the participants, i.e. the knowledge component of the collaboration rather than social or situational components. Therefore, although context effects, socio-cultural variables, and other non-knowledge level individual differences will influence many aspects of the collaboration (e.g., as suggested by Harrison & Minneman, 1995), they should not alter the process implicit in the knowledge level of the participants.



**Figure 17: Model of collaborative design**

Social/psychological variables, which are unrelated to the task-specific knowledge of each participant may affect things, such as the degree to which the collaboration is enjoyed or disliked. However, the real result of the collaboration, in this case an architectural design, will be largely the consequence of the problem-related knowledge and experience of each collaborator.

If our model is correct then the tools used to support collaborative work should focus on facilitating the meta-planning, negotiation and evaluation components of the process. Otherwise, the tools should be no different from those used for individual work, except for requiring a means to share the results.

## 5.7 Design Process Model

As described in Chapter 2, collaborative architectural design can be seen as having two aspects: a collaborative process, as discussed above, and an architectural *design* process. Design consists of a large number of activities which can be considered to fall into four broad categories. Initially, designers digest the information given, gathering and reading facts and determining the data at hand. These we called *task-focused* activities. Next the designer strategises solutions, making broad decisions which will affect significant aspects of their later decisions. These we call *high-level design* (HLD) activities. These activities include planning the site, laying out major components and identifying primary routes. Once these have been completed, *low-level design* (LLD) activities can be expected to start, such as placing individual elements such as trees, benches and parking places into the framework set by the high-level design actions, resolving issues of drafting (e.g. line type) and drafting actions. Thus, a prototypical design flow by someone exhibiting expert behaviour will have more HLD at the beginning of a design session and more LLD later in the session. Among all of these activities we can expect the designer to need to deal with the particular medium within which they are working. If they work in pencil and paper, it would include things such as sharpening the pencil. In our context, these *interface-specific* activities address issues of menus, commands, and connections.



## 5.8 Predicted Outcomes

Performance was measured in terms of the quality of the final output. Quality is a difficult dimension to measure explicitly in a design but implicit measures can be used. In this experiment, we gave the design results to teaching staff to evaluate. We asked them to rank the designs within the set. In the case of Condition 1, the criteria used for ranking the designs were those which the staff agreed were used in a typical face-to-face design studio — the quality of space resulting and the degree to which the design met or exceeded the programme requirements. In the second condition, an additional ranking was obtained by asking the teachers of the educational psychology course to identify criteria by which they would measure success in the design and to then rank the designs on the extent to which they met these criteria.

The quality of the final output is contingent on the ability of the designers to accommodate the particular computer-mediated interface's information-sharing characteristics to their expert task. We therefore examined collaborations using video conferencing (high band-width) and chat-line (low band-width) with the expectation that subjects would create more efficient meta-plans under the low band-width condition.

In addition, the method of communication was expected to influence the distribution of types of design communication exchanges. We expected to see fewer exchanges with low band-width channels, of which a greater proportion would be HLD exchanges since the burden of the interface makes it impractical

for low value exchanges. Inversely, higher band-width communication would be more profligately used.

## 5.9 Results: Condition 1

The protocols were coded according to the two models, one to extract the *collaborative* process engaged and the other to extract the *design* process employed by the participants. A chat-line protocol and a video/audio protocol were first selected and extensively reviewed by the two coders. Once the coding schemes were finalised, all of the sessions were coded by one coder for the Collaboration Model and by the other coder for the Design Model. Finally, each cross-checked the reliability of the other coder by independently coding one protocol under the other's model. For the Collaboration Model, the inter-rater reliability was 86% with a Cohen's kappa = 0.768 while it was 62% with a Cohen's kappa = 0.52 for the Design Model. Finally, all design products were graded by teaching staff in the Department of Architecture to determine their design value.

An average of 49 communications were encoded in each session of the chat line setting and an average of 137 exchanges were encoded in the audio/video setting in Condition 1. In Condition 2, where the participants did not share the design knowledge domain, the average encoded communications in chat line was 52 and in audio/video was 320.

### 5.9.1 Design Evaluation

We will report first on the evaluation of the finished designs since this is, perhaps, the most surprising result. In order to evaluate the quality of the finished designs, we had the designs independently graded by two lecturers from the University of Hong Kong's Architecture Department. Agreement between the two markers was high (80% overlap in the rank order of the grades). The disagreements were minor and were resolved through discussion. Subjects were graded according to the percentage of the required design tasks they completed, the degree to which they satisfied the technical requirements of the tasks which they did complete, and the overall quality of their design. A reliability analysis revealed an Alpha coefficient of 0.877 indicating that all three measures were tapping the same construct, which we assumed to be a general competency for the task. Taking an average of the three measures to create an overall score, the two groups (video/audio versus chat-line) showed no difference, both producing a mean overall score of six out of 10. Although the number of subject pairs was too low to rule out any effect for the conferencing technology we could rule out the existence of any large systematic effects. This, despite the very real limitations imposed by the bandwidth in the chat-line condition (i.e. in the video/audio condition, subjects could talk and draw at the same time whereas in the chat-line condition they could only do one at a time).

It should also be noted that there was considerable variability in the final design products and the ways in which they were created. For example, some subject



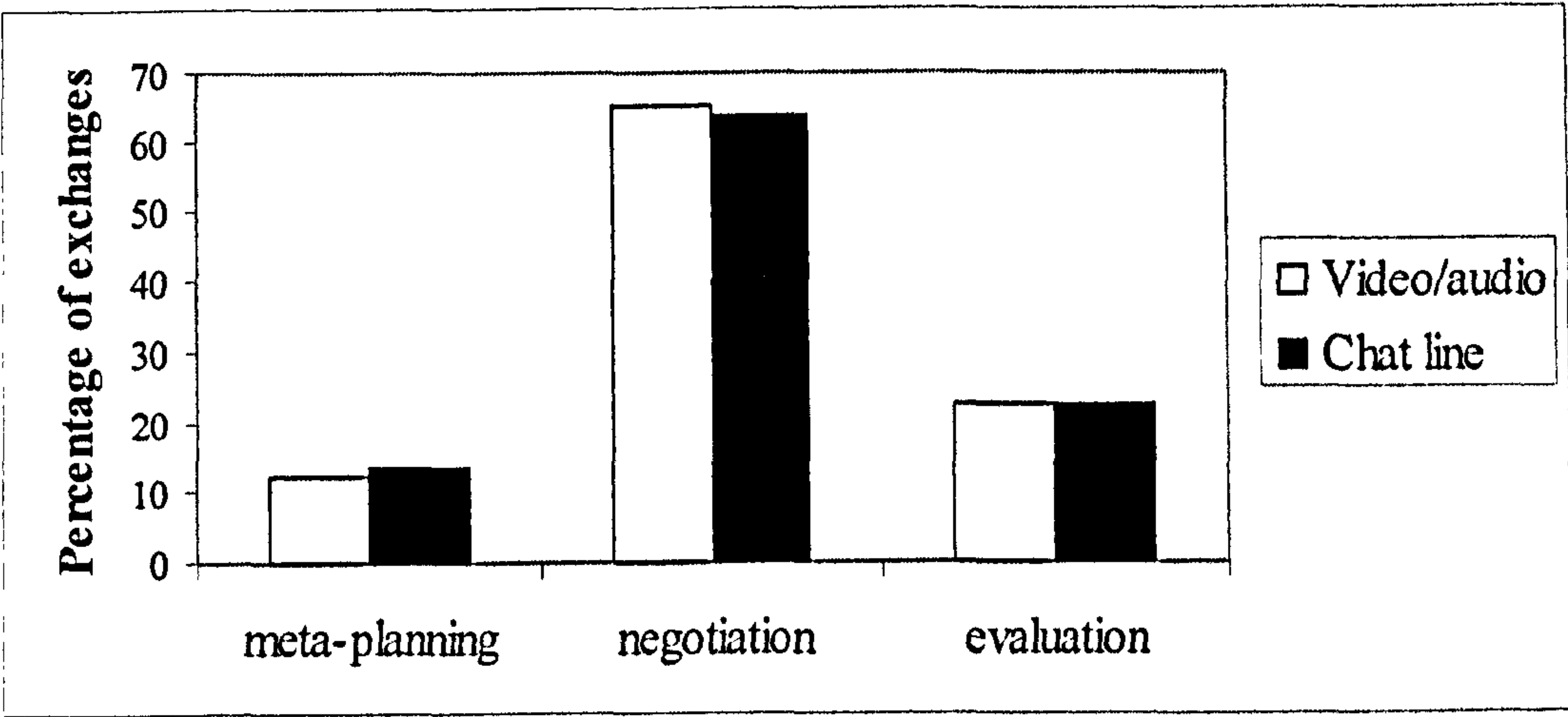
pairs worked together on each design element while others worked in parallel on different elements. Also, some subject pairs worked in a very egalitarian, democratic manner while other pairs were dominated by a single authoritarian subject.

### 5.9.2 Collaborative Process Encoding

Overall, the protocols of participant pairs in the video/audio condition had approximately twice as many exchanges as those of participant pairs in the chat-line condition. Given that the final performance on the task was the same between the two conditions, one has to wonder how the participants in the chat-line condition made up for the overall decrease in communication.

Our initial hypothesis was that the chat-line participants achieved this by increasing the relative amount of meta-planning they did during the task. Meta-Planning, includes dividing-up the task (e.g., "So maybe we can have a division of labour: I deal with the access and you deal with the car park, OK?"), planning the order of task execution (e.g., "I suggest that we identify the plan first before we start to do anything."), and strategies for completing the task (e.g., "So we have to do the sketch design first before any calculation."). The other communicative activities participants demonstrated were Negotiation (e.g., "I intend to erase some of the seating, what do you think?") and Evaluation (e.g., "The car park is too small, I think.") The fourth element included in the Collaborative Process Model was *Individual Work*. Although there was some verbal evidence of it in the

protocols (e.g., "OK, I'm drawing trees now."), a review of the videotapes of the sessions showed that it was going on continually though out the design process.



**Figure 18:** Results of coding the Condition 1 protocols with the Collaborative Process Model.

As stated, we expected that the amount of Meta-Planning would increase while Negotiation and Evaluation would decrease in the chat-line condition, thereby accounting for the lack of difference in the quality of the finished designs. This was not the case, however, as Figure 18 shows. The total amount of each type of interaction decreased *proportionately* from the video/audio condition to the chat-line condition. As the number of participants was relatively low, it is important to note that the aggregate pattern shown in Figure 18 was demonstrated by *all* the collaborator pairs. The correlations among the patterns of communication shown by subject pairs were all above .7 and significant at the .05 level.

This extremely consistent pattern along the three categories indicates that the collaborative process was undisturbed by the two very different communicative

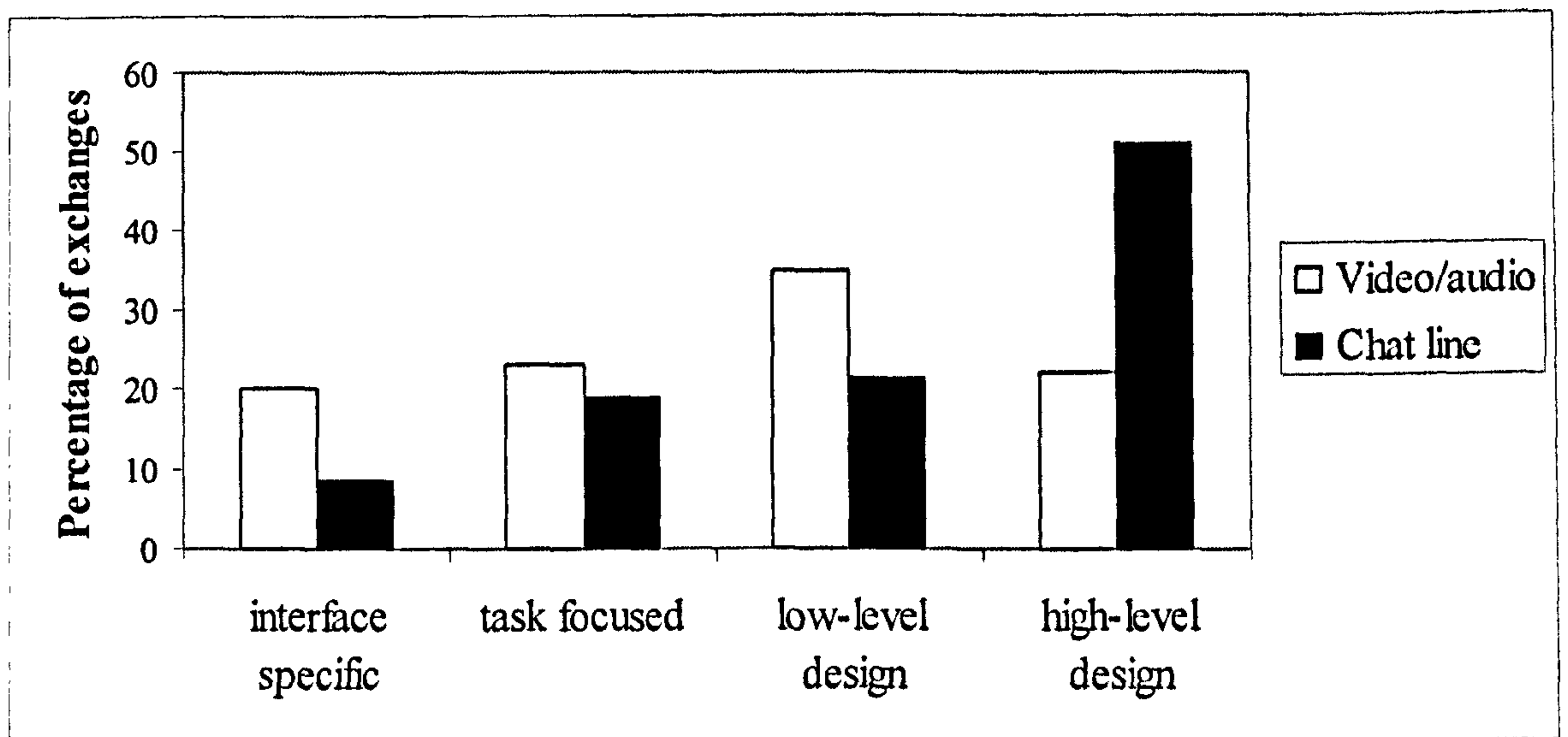
conditions. It also suggests that this approach to breaking down the collaboration captures something essential about the process. Given two different modes of communication, participants in both conditions maintain a very similar pattern of collaboration (a ratio of Meta-Planning to Negotiation to Evaluation of 1:5:2). The Collaborative Process Model therefore successfully describes the way in which people engage in collaborative work by strategising, dividing-up the task and temporally ordering the activities, regardless of the nature of the communication mode.

These findings are similar to those of Olson et al (1992) who categorised protocols from meetings using a coding scheme much like ours. They coded interactions into three clusters of categories: Co-ordination/Management Activities similar to our Meta-Planning category, Direct Design Activities similar to our Negotiation category, and Summary/Walkthrough Activities similar to our Evaluation category. The relative percentages of these three clusters were 27%, 43%, and 30% respectively. Although, different to our results in terms of the magnitude of the differences between the three categories, the relative pattern was similar. The magnitude difference may be the consequence of the fact that *co-ordination* and *design* activities were not distinguished in their coding scheme. The two models proposed here pull apart these two kinds of activities. The Collaboration Model focuses exclusively on the collaboration (i.e. co-ordination) aspects of the interaction while the Design Model captures the other side. We would therefore argue that the larger differences between the categories found in



our experiment are the consequence of using two separate models to code the protocols, resulting in a more sensitive instrument to evaluate the content of the interactions.

Given that there was a 60% decrease in the total number of exchanges in the chat-line condition (distributed evenly over Meta-Planning, Negotiation, and Evaluation), one would expect to find a significant negative impact on the design outcomes. Since the Collaborative Process Model does not provide an explanation for why the design outcomes were equivalent in the two conditions, another explanation is necessary. As indicated above, we expected that the relative amount of Meta-Planning would increase in the chat-line condition, counterbalancing the effect of fewer exchanges. The results from the Collaborative Process analysis could not be clearer, however — there was no change in the ratio of the types of exchanges. Something else must have been at work, something not captured by the model, that allowed subjects in the chat-line condition to produce equally good designs. Our next hypothesis was that it was related to *what* work was carried out collaboratively as opposed to the allocation of the work between the participants.



**Figure 19:** Results of coding the Condition 1 protocols with the Design Process Model.

### 5.9.3 Design Process Encoding

It would appear that more restricted channels of communication require more selective exchanges of communications and that the communication sacrificed would be low content-level exchanges. Thus, the differences between communication modes might appear in the Design Process Model but not in the Collaborative Process Model.

In order to evaluate the nature of design communication, all exchanges for the sessions were reviewed and encoded as one of the four following types: *Task Focused*: (e.g., reading the instruction), *Interface specific* (e.g. "Sorry, can you speak louder."), *High-Level Design* (HLD) (e.g. "I propose a zigzag route from here to here"), and *Low-Level Design* (LLD), (e.g., "what colour do you like for the seating?").

Coding the protocols this way showed a clear difference in the content of the chat-line condition to that found in the video/audio condition. Chat-line communication contained a notably higher percentage of HLD content, 50% of all exchanges, compared to video/audio, where only 22% of all exchanges were HLDs. *The ratio of LLD to HLD was inverted*, with chat-line showing proportionately more HLDs than LLDs while video/audio showed the opposite effect. (see Figure 19). Basically, participants in the chat-line conditions made up for having a narrower communication channel by decreasing the amount of LLD in order to maintain a high number of HLDs. The participants also sacrificed the other two types of communicative exchanges to achieve the high proportion of HLD exchanges in the chat-line: Task-Focused was 19% for chat-line and 24% for video/audio; Interface Specific was 8% for chat-line and 20% for video/audio. Participants in the video/audio condition, on the other hand spent a much greater proportion of their time discussing Low-Level Design issues as well as Task and Interface issues. As in the Collaboration Model, the pattern of results found for each pair of subjects was very consistent with the aggregate data. For the chat-line condition all pairs except one showed the pattern in Figure 19. The same was true for the video/audio condition.

The fact that the chat-line collaborators did just as well on their designs as the video/audio collaborators suggests that it is the HLD exchanges that play the more significant role in determining the quality of the outcome. Most importantly, the nature of the communication mode would seem to have little effect on this aspect



of collaborative work as participants appear to implicitly adapt to communicative constraints by either increasing or decreasing the amount of low-level discussion.

## 5.10 Results: Condition 2

The protocols for the second condition, where Design students were paired with Educational Psychology students, were coded in the same way as those in Condition 1. The final designs were also evaluated as in Condition 1 except that, this time, they were rated by two Educational Psychologists as well as by two Architects, representing the two orthogonal domains of knowledge. At the outset we expected the results of Condition 2 to be the same as Condition 1. We will report on the results of these evaluations first.

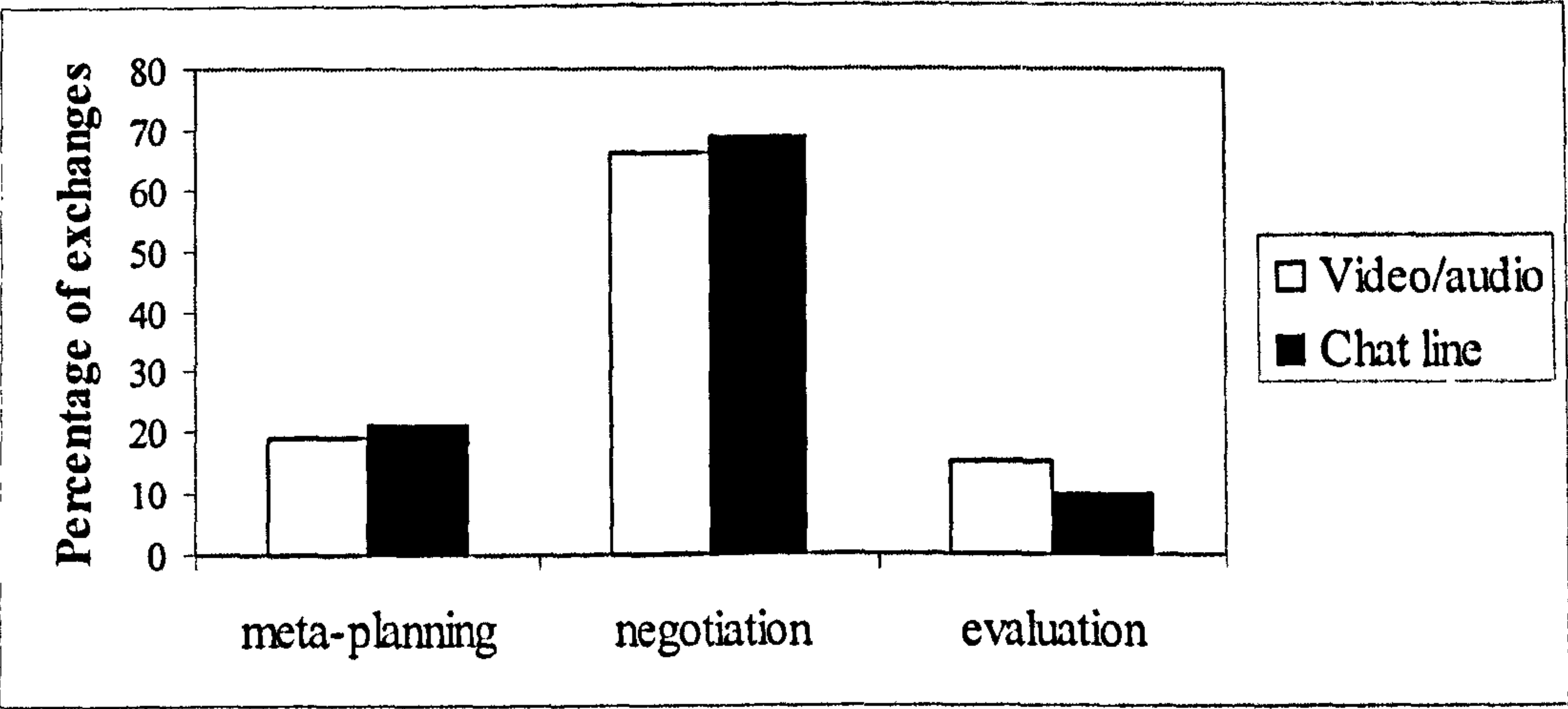
### 5.10.1 Design Evaluation

Two professional Architects were once again asked to rate the designs. They rated each design in terms of the *creativity* of the solution. The two Architects' ratings on this criterion were reasonably correlated with one another ( $r=.64$ ). The findings here were the same as in Condition 1: there was no significant difference between the two bandwidth conditions in terms of the quality of the final designs. In fact, the chat-line condition did slightly better, overall, than the video/audio condition although the difference was not statistically reliable. A significant difference was found, however, when professional Educational Psychologists were asked to rate the final designs.

Two Educational Psychologists were first asked to generate a set of criteria along which playground designs could be evaluated. The most important criterion, according to both professionals, was *safety*. They were then asked to independently rate the eight completed designs along this criterion. The correlation between their two ratings of the eight designs in terms of their safety was .65. Furthermore, the designs produced by participants in the chat-line condition were found to be significantly better than those generated by participants in the video/audio condition (Mann-Whitney Test,  $p < .072$ ). For all of these evaluations, the raters were, of course, blind to condition in which the designs were generated.

### **5.10.2 Collaborative Process Encoding**

Figure 20 shows the results of the Collaborative Process Model encoding. The pattern of results observed between Meta-planning : Negotiation : Evaluation was similar to that found in Condition 1, although a slight increase can be seen in the proportion of Meta-planning offset by a corresponding decrease in the proportion of Evaluation, while the proportion of Negotiation remained the same. The difference between the patterns of results in the two studies was not statistically significant. Again, similar to Condition 1 the pattern of communications was observed in all subject pairs, not only in the aggregated data.



**Figure 20:** Results of coding Condition 2 protocols with the Collaborative Process Model.

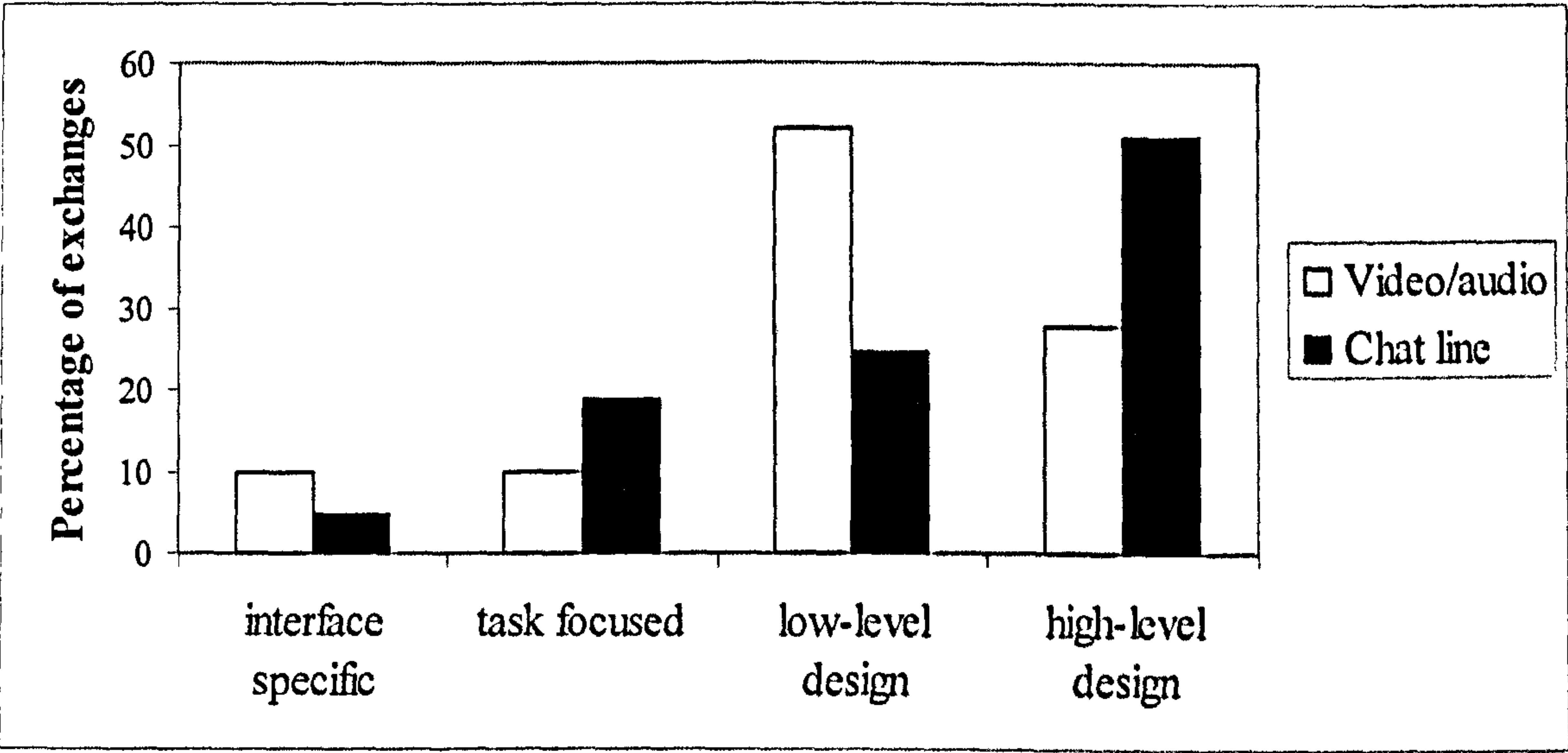
### 5.10.3 Design Process Encoding

Here we see a similar different pattern of communications when compared to Condition 1. The ratio of HLD to LLD communications in Figure 21 is again inverted between the video/audio condition to the chat condition. The proportion of low-level design communications in the video/audio condition, however, was substantially higher than that in the chat-line condition. Although it is not apparent from Figure 21, it was the Educational Psychology students who contributed a majority of the low-level communications in these sessions. These results might be attributable therefore to a difficulty encountered by the Educational Psychologists in differentiating between important and unimportant design communications.

A second interesting finding is the distribution over time of high and low level exchanges. In the video/audio conditions, almost all the high level



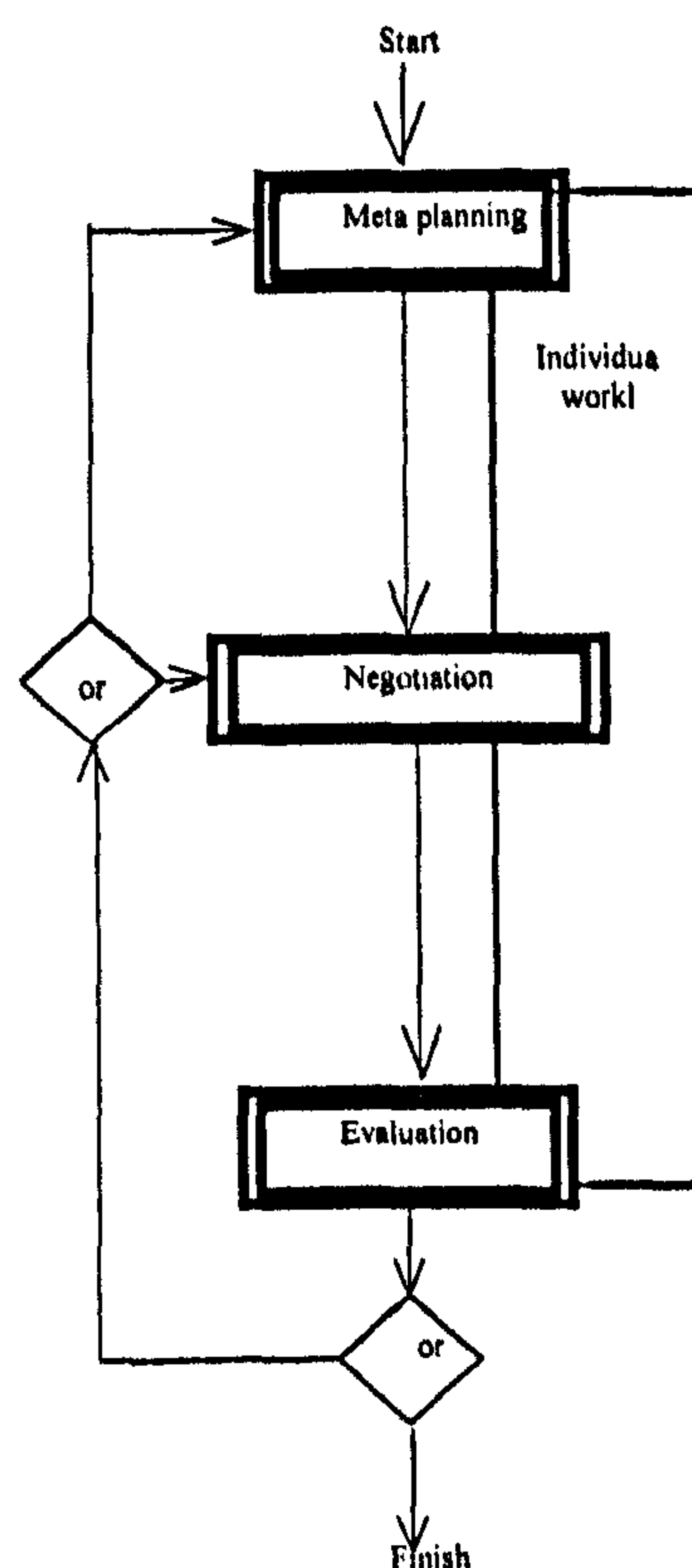
communications occurred in the first half of the exercise whereas in the chat-line condition, high-level exchanges were evenly distributed throughout the collaboration. This pattern was statistically significant ( $F=11.96$ ,  $p<0.005$ ) and present in all subject pairs except one chat-line condition in which the Education Psychologist generated almost no high-level communication, apparently being unable to distinguish between important and unimportant issues of design.



**Figure 21:** Results of coding Condition 2 protocols with the Design Process Model.

## 5.11 Discussion

Reviewing the findings we see that collaborators do not follow the process proposed in our model of collaboration as tidily as expected. Processes of individual work appear at many points and are inherently difficult to discern. Based upon our observations, a revised model which could be derived from the observations might be something like that shown in Figure 22.



**Figure 22:** Derived cognitive model of collaboration

In this re-representation of the model, we find the individual work always present, but proceeding independently of, and along side, the collaborative effort. The

outcomes of the collaborative control processes inform the individual work, determining what work is done in particular but the collaborative control mechanism is not integrated into the work at hand.

Building from research that suggests collaborative interfaces must involve a high throughput of information (e.g., tonal inflections, gestures, voice, and so on), we started with the assumption that designers faced with limitations in communication bandwidth would adjust their collaborative strategy to compensate for the restrictions in communication. Instead, we found the collaborative strategies to be the same. Compensation obviously had to occur since there was a marked reduction in the amount of communication.

Domains of knowledge had a discernible effect on the nature of communication. We found compensation occurred in the *content* of the communications, not in the *strategy* of collaboration when the two participants share expertise in the domain of design. As band-width was reduced, subjects shifted the content of their exchanges from discussing low-level issues to engaging in much more high level discussion. We also found a marked reduction in the number of task-related exchanges and comments on the interface during chat-line communication. In contrast, when the two participants did not share the same domain of expertise, there was an increase in the amount of strategising, as indicated by a 50% increase in meta-planning between Condition 2 and Condition 1. Furthermore, the ratio between HLD and LLD was consistent and similar in both studies for the Architecture students but not so distinct for the Educational Psychology students.



This suggests that the chat-line subjects worked more independently, collaborating primarily when strategising. While not the expected compensation mechanism, the outcome is not surprising. This important shift in balance between HLD and LLD occurs without any explicit discussion between the subjects; there was no evidence that participants were even aware of making a shift in their own communications.

An alternative interpretation of the results is that it is the subjects in the video/audio condition who are doing the tacit adaptation to the extra bandwidth. As bandwidth becomes available it is filled with an increasing amount of low-level discussion, just as an open phone line might be filled with noises to convey presence and not content (noises such as throat clearing or social niceties). This interpretation is supported by the fact that, at least according to one of the measures of design quality in Condition 2, the products of the chat-line condition were superior to the video/audio condition. The additional bandwidth in this case seems to have had the role of introducing elements that reduced final quality.

The research described here challenges assumptions evident in much previous research in the field of computer-mediated collaborative design. Typically, previous work has been driven by the need to recreate a “design space” in all its properties, without critically evaluating the contribution of these properties to design outcomes. An example of such work is that found in Tang (1991). Here, the author identifies actions of “writing, freehand drawing and gesturing activities

that occur when three or four people work around whiteboards or large sheets of paper,” (p.143) noting that

“Collaborative drawing tools should not be based only on what features computer technology offers...the design of collaborative technology needs to be guided by an understanding of how collaborative work is accomplished. By understanding what resources the collaborators use and what hindrances they encounter in their work, tools can be designed to augment resources while removing obstacles.” (Tang, 1991, p. 143)

While agreeing with this point that the design of tools for collaboration should be based on a good understanding of the process, Tang goes on to conclude that gestures are as important as any other communication and that

“design of tools to support collaborative drawing activity should consider:

- conveying gestures, maintaining their relationship to the drawing space;
  - conveying the process of creating and using drawings, with minimal time delay;
  - providing concurrent access to the drawing space;
  - allowing intermixing among drawing space actions and functions; and
  - enabling all participants to share a common view of the drawing space.”
- (Tang, 1991, p. 156)

This implies that the context, in a situated sense (Suchman, 1987), is important. We have found that the context is not an over-riding factor in successful collaboration. While it cannot be denied that the context within which an activity is carried out will affect the outcome, it is clear that we are, as humans, adaptive to our environment (the subjects changed the nature of their communication according to the mode and bandwidth) and adaptive of it (the subjects resized and moved windows on the screen as tasks demanded it). That users adapt successfully to the quality and capabilities of the tools at hand is widely noted in studies of the application of computer tools (e.g. Moran, et al., 1996; Scrivener,

Urquijo & Palmén, 1996; Kurland & Barber, 1996). Although we exist in an environment with infinite levels of complexity, we solve each problem and make each decision in a much more restricted informational context (Simon, 1996). So it is in any collaborative communication — we adapt to it and we adapt it to our needs. Since our individual cognitive systems are not built to cope with the full complexity of the environment at any one time, we pick out what is relevant and necessary in order to proceed.

The pattern of problem-solving found in this experiment reflects the knowledge the subjects had (from their classes) regarding how to solve this kind of problem. More importantly, it reflects a collaborative mechanism whereby the nature of the communication itself is implicitly shaped to the nature of the communicative mode without any loss in the quality of the collaborative outcome. The consistent allocation of time or effort in different stages of collaborative process found across our different bandwidth conditions mirrors the consistency found by Olson, et al. (1992) and Olson, et al. (1996) in their analysis of design meetings. As with the chaotic activities which constitute a face-to-face meeting, the messy data recorded during our design studies shrouded consistent patterns of work.

So, although the collaboration *looks* very situated, it is in reality shaped and guided by the collaborators' individual knowledge of the task and their tacit ability to adapt to communicative situations.



Much has been said recently about the special nature of collaborative work, especially on open-ended, creative problem-solving tasks such as architectural design (Tang, 1991; Harrison & Minneman, 1995). Our findings, however, paint a simpler picture: experts in a particular area of knowledge solve problems in consistent and regular ways. Moreover, the process of collaboration is remarkably consistent along certain dimensions and remarkably adaptive along others.

## 5.12 Conclusion

The results of this experiment suggest that there is negligible influence of communication mode on the collaborative execution of expert tasks when the same domains of knowledge are represented at both ends. The participants in this project carried out their collaborative tasks using the same collaborative process (Meta-Planning, Negotiating and Evaluation) regardless of the communication mode. Altering the communication channel did have an effect; the profile of communication content changed (i.e. the ratio of HLD to LLD) but, importantly, the change in communication modes did not influence the design outcome. This change was noted in both knowledge domain conditions, with a clear increase in the number of low-level communications in the condition with two different knowledge domains in the collaboration. Thus, we conclude that collaborators adapt the nature of their communication to the bandwidth of the channel available without compromising their collaborative strategy or expert contributions.

That the communication bandwidth or technology had no effect on the outcomes of the task is resonant with the findings by Kraut, Miller & Siegel “We found no evidence that differences in communication technology influenced success in collaboration” (Kraut, et al., 1996, p. 64). This finding is also consistent with Olson, et al. (1997), although they note that a significant deterioration in design quality was found when comparing face-to-face to non-video (audio only) communication. It is also consistent with the findings by Tang & Isaacs who go on to observe that the participants in a video condition found the interactions “more satisfying” (Tang & Isaacs, 1993, p. 192) even though the task outcomes were no better.

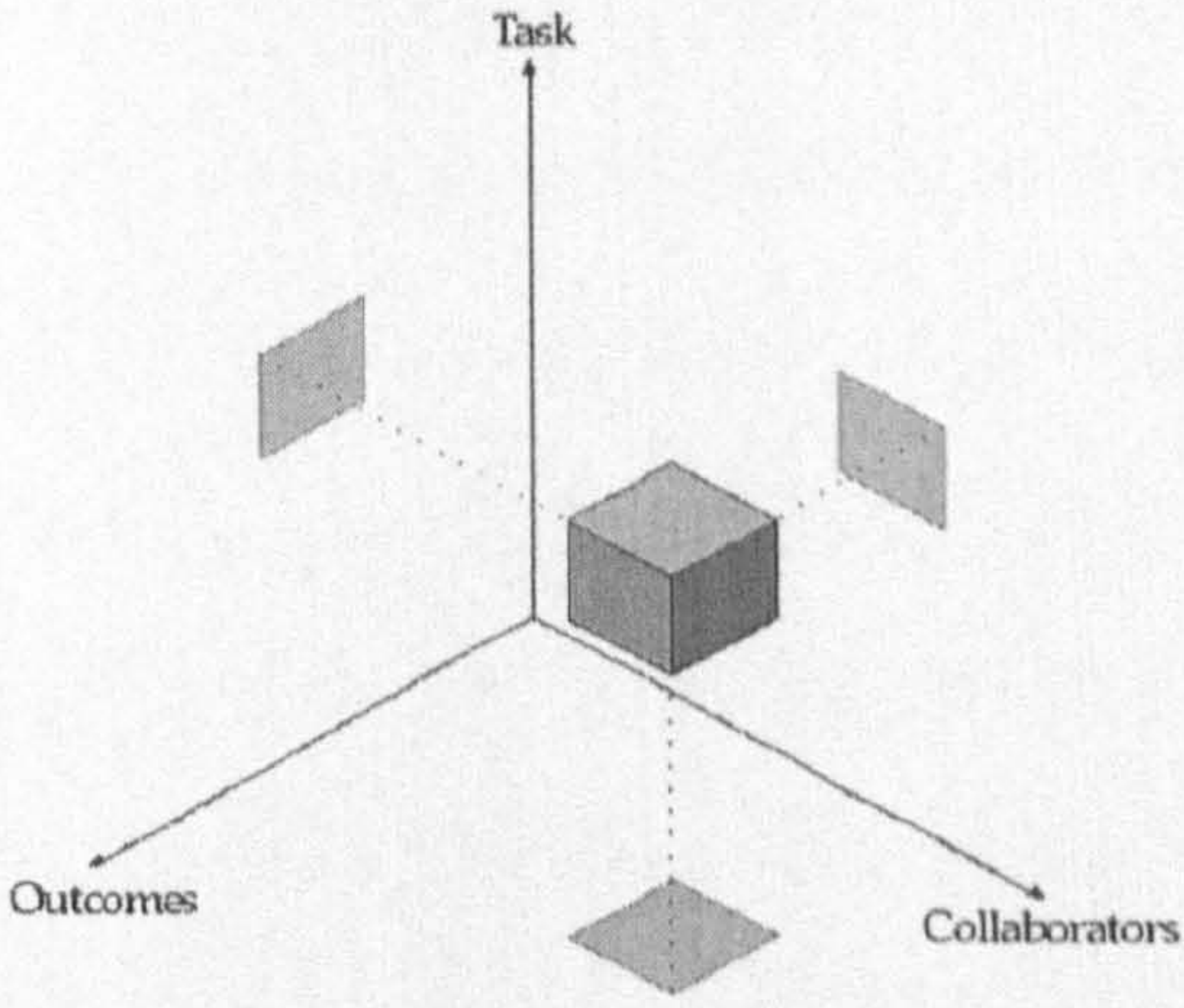
The findings presented are not intended to be interpreted as suggesting that the nature of the communication mode *never* makes a difference in collaboration. Rather these results are one data point in a space of possible combinations between *task* (i.e. design, meeting, conflict resolution, social, etc.), *types of collaborators* (i.e. relative knowledge, social/hierarchical relationship, etc.) and *outcome measures* (i.e. quality of output, solution of problem, individual satisfaction, etc.), as shown in Figure 23. Each box in the space needs to be filled in with the tools necessary to achieve the specific goals of the collaboration. It may be valuable to view one goal of CSCW research as filling in the different boxes in this collaboration space.

We have filled in two boxes, each with a well-defined design task, two knowledgeable collaborators (in one case with similar backgrounds, in another

with orthogonal domains of knowledge) and quality of design as an outcome measure. Nevertheless, these findings, especially the implicit shift in the level of communicative exchanges, beg an explanation. One approach to explaining this shift is to cast the problem in terms of the context within which the activity was carried out. In design terms, this would suggest that the events within the design process were influenced substantially by the tools and nature of the exchanges experienced, in other words within a situated view of the activity. Instead, the consistency of the behaviours between experimental conditions suggests that participants are reacting in a way conditioned by their training and knowledge bases. As they encounter a new medium for design communication, they have adapted their means of communication. This shift is that observed by Kurland & Barber (1996) in other contexts of electronic collaboration.

From this perspective, we see design as being *deliberative* behaviour of a professional (Eraut, 1994, p. 121) or a *knowledge-level* response as postulated by Newell (1981). The participants are working in a situated setting where information is distributed among participants and in the worlds they inhabit. Nevertheless these studies suggest that the outcome of tasks requiring domain-specific knowledge is a consequence of an integration of these different sources of information by each participant. That is, the behaviour we see is one of expert actions rather than situated actions.





**Figure 23:** Space of collaboration characteristics requiring different computer-support solutions

There are then implications for interface design — if collaborative work is much like individual work within this model, then a collaborative interface need not be different. Furthermore, if the designers can adjust to their level of communication and achieve the same outcomes, there is no need to compromise an interface by providing excess communicative information. Indeed, we suggest that when greater bandwidth is available, the core activity of design does not change but that the available capacity is taken up with lower level communications that do not enhance the design product.



## **6 Pedagogical Applications of CSCD**

Having developed an understanding of the context of collaborative architectural design and the tools needed for CSCD in the preceding chapters, this chapter examines the questions and opportunities which present themselves in teaching in a VDS. Based on reviews of problem-based learning and examinations of architectural studio learning, including several experiences in conducting virtual studios, the particularities of conducting a studio in the virtual world will be considered, the motivations for these studios, the experiences of students and the results obtained. From this background, benefits and drawbacks of teaching in this manner can be identified, leading to guidelines for framing and conducting effective and successful virtual design teaching.

There is much debate about the teaching of design. This chapter will present some of the arguments but will not engage in the debate to the extent it might — we are only attempting to understand the application of computer-mediated collaboration within the design studio. As suggested in Chapter 1, however, the introduction of a computing technology requires us to reconsider what we do at present and not try simply to automate our current ways, be they methods of production or teaching methods. A more complete examination of the issues needs to be undertaken. Such a review is a substantial undertaking in itself and beyond the scope of this thesis. Examples will be given to illustrate aspects of the issue as discussed in this chapter.

## 6.1 Introduction

As students or teachers of architecture, we are all familiar with the elements of design studio teaching: the setting of a design problem in the form of a brief or programme, the explanation and exploration of the brief by the students, presentations of ideas and reviews of proposals. What makes this setting effective for architectural education and how does a virtual design studio fit? In order to limit the discussion, I shall address the teaching that occurs in a typical first design degree setting, commonly an undergraduate degree.

Before discussing some of the specific pedagogical issues that arise in a VDS, I will first address a fundamental question — why do we even consider teaching in Virtual Design Studios. After that, I shall look at specific pedagogical issues that



come into question when conducting a design studio with some or all participants in remote locations. To do this, I shall consider the following topics for both traditional studio teaching and teaching within a virtual design studio:

- What do we do in studio teaching
- Settings for design teaching
- The teaching compact
- The contribution of the studio master (or tutor)
- Peer learning
- Learning resources available to the student
- Reviews and juries

Each of these topics is considered first by examining current studio teaching, then changes needed for virtual design studio teaching will be discussed. These aspects of a VDS are then brought together in a discussion in which the issues are reformulated in the framework of problem based learning. From this, a conclusion is presented regarding the development of virtual design studios.

## **6.2 Design studio teaching**

Our approach to teaching is necessarily structured within a theoretical attitude to architecture itself. The extent to which this holds is often a defining characteristic of the particular school of architecture. Much technical teaching outside the studio is conducted within the logical positivist epistemology, encouraging students to consider architecture as a technical and rational process of problem solving as

framed in Simon (1996). As discussed in Section 2.4, this approach leads us to teach problem seeking, the heuristics of problem solution and search techniques.

In some schools, this approach is extending to studio teaching, but in most a dichotomy exists because studio design teaching is carried out under a different approach, that presented by Schön (1985; 1987). As Schön states it,

the problems of real-world practice do not present themselves to practitioners as well-formed structures. Indeed, they tend not to present themselves as problems at all but as messy, indeterminate situations. (Schön, 1987, p. 4).

These ill-formed problems, Schön observes, do not lend themselves to the technical rational approach. The problems can be ill-formed because of a multitude of conflicting demands, because the solutions present themselves with conflicting outcomes or because the problems appear to be unique and do not fit any prior model. His proposal is that we solve these problems through interaction with them, either through "naming and framing" the problem so that it (or its components) fit within the technical problem solving approaches which we are equipped to handle (Schön, 1987, p. 5). He calls this ability to discover a solution "thinking as an architect" (Schön, 1987, p. 35).

In Schön's presentation, the role of a design studio is, therefore, an opportunity for the students to observe and engage in reflection-in-action. Where Simon (1996) sees the design studio as a place to teach designing as problem solving, Schön sees designing as making (Schön, 1987, p. 41), a process of converting the indeterminate into determinate by constructing a coherence. Under this model, design is a "web of projected moves and discovered consequences" (Schön, 1987,

p. 42). By analysis and criticism the students discover the consequences and implications of their decisions. The discovery results from the students observing the studio master's reflections on design made as comments or drawings while he is reviewing ideas or critically evaluating student work. Through this process the students share in the tacit knowledge which is so important to the success of an architect.

### **6.3 Problem based learning**

A typical studio presents students with a real design problem, often taken from the design offices of one of the teachers. Students are encouraged to explore solutions, encountering failure, success and frustration along the way. This approach, which we have practised as studio teaching, is very similar to the more articulated theory of Problem-Based Learning (PBL) (Bouhuijs, Schmidt & van Berkel, 1993); indeed, there are very great similarities between Schön's formulation of studio teaching and the methods of PBL (Cowdroy & Maitland, 1994). PBL was first formulated some twenty years ago to address perceived shortcomings of medical education (Koschmann, et al., 1994, p. 240). Ostwald & Chen (1994) note that PBL is now found in many professional or vocational courses, having been adopted by the fields of architecture, law, engineering and construction management.

The essence of PBL is the posing of a problem for which the students seek solutions through their self-directed explorations, thereby accomplishing self-



directed learning. They engage in a search for solutions, learning not only the facts of the situation and the solutions but also the process. For example, they may embark on proposing solutions immediately, only to discover that they must instead engage in the search for the issues and then for the solutions. In this process they engage in discussions with peers and teachers to understand their work. In a model of PBL for medical teaching, Koschmann, et al. (1994) identify five stages of the learning process: problem formulation, self-directed learning, problem re-examination, abstraction and reflection. The first three stages are linked by circular loops that permit the students to return and reenter the preceding stage as they explore the problem. This reflects the process by which architectural students engage design problems. Architectural studio education differs from the model present by Koschmann, et al. at this point. Once our students have reached a solution they present this to a jury and have to engage in a public justification of their proposal. What we appear to miss are the last two steps, abstraction and reflection.

Koschmann, et al. (1994) propose six principles of effective learning and instruction which they consider critical in the learning of complex and ill-structured fields. These six principles are then translated into the field of PBL to develop a set of specifications for collaborative, case-based or student-centred learning. The learning of architecture matches their description of complex and ill-structured fields (Koschmann, et al., pp. 230-231), fields in which concepts do not stand alone, interact with and are co-defined in a complex fashion, making

learning in isolation problematic. As noted earlier, many architectural problems fall into the category of wicked (Rittel & Webber, 1973; Cuff, 1991; Goel & Pirolli, 1992), problems which are ill-structured and fall into ill-structured domains. Koschmann, et al. propose that such problems are best engaged with six principles in mind, summarised in Table 5.

Architectural studio education fits this model very closely — students are required to tackle problems which are ill-structured in several dimensions (multiplicity); the solution to the problem can only be found by engaging actively in a variety of tasks from cognitive to skill-based (activeness); students have to absorb and accommodate their findings as they discover new facts or approaches (accommodation and adaptation); the problems are typically taken from real situations and consultants or clients brought in the course of the studio (authenticity); students have to present their work in a variety of forms and media, often in a public setting before their peers or visitors (articulation); professional societies in many parts of the world now require continuing education in order to maintain a license to practice (termless). As Koschmann, et al. demonstrate, PBL accommodates these six principles very well. So too can teaching in a VDS.

**Table 5.** Principles of learning and effective instruction in domains and problems that are complex and ill structured  
(from Koschmann, et al., 1994)

Principle	Definition
Multiplicity	Knowledge is complex, dynamic, context sensitive and interactively related; instruction should promote multiple perspectives, representations and strategies
Activeness	Learning is an active process requiring mental construction on the part of the learner; instruction should foster cognitive initiative and effort after meaning
Accommodation and adaptation	Learning is a process of accommodation and adaptation; instruction should simulate ongoing appraisal, incorporation, and/or modification of the learner's understanding
Authenticity	Learning is sensitive to perspective, goal, and context; instruction should involve authentic activities, settings and objects of study
Articulation	Learning is enhanced by articulation, abstraction, and commitment on the part of the learner; instruction should provide opportunities for learners to articulate their newly acquired knowledge
Termlessness	Learning of rich material is termless; instruction should instil a sense of tentativeness with regard to knowing, a realisation that understanding of complex material is never "completed", only enriched , and a lifelong commitment to advancing one's knowledge

To understand the pedagogical facets of VDS teaching, we need first to review traditional studio teaching. The goals of a VDS are as varied as the goals of a design studio in a single physical place. The nature of the studio must be established to attain the pedagogical goals, not dictated by the technology employed. Typically, a virtual studio is configured to cause students to participate



with students in remote locations in the exploration of architectural solutions for problems defined to be shared by each remote location. The challenge for the studio master is to establish a task for the studio which *requires* collaboration, something which cannot be completed by immediately dividing into individual parts. For example, in a VDS in 1997, students in Hong Kong were teamed with students in two other institutions, the University of Oregon in Eugene and UBC in Vancouver. They were required to work together across time and space to design a building in either Vancouver or Hong Kong which expressed the essence of the other location. The resulting building would be, for example, one which a person in Hong Kong could visit and experience some part of Vancouver. To achieve this, every student started by building a web page which described a place which they thought expressed an essential part of their experience of their home location. Pairs were then formed between locations and the pairs asked to choose one of the essences and create a structure in the other location to express that essence. Final presentations were made on web pages located at either node. The project definition required the students to engage and understand their partner.

In another VDS experience, the students worked on a shared design programme. Groups were formed at their each school, but shared their ideas across the web to other schools and discussed the proposals of other teams in other locations. Thus, the students in Hong Kong designed buildings for Shanghai as did students in five other universities, each team looking at the others and commenting as the designs progressed. The collaborating in this example was looser, but students came to see

and understand work produced at other schools. In a third configuration, we have run design studios in Hong Kong linking the two schools of architecture locally, taking students over by bus to visit each other as well as collaborating using the Internet. Thus, we have tried a wide variety of situations to varying effects.

### **6.3.1 What are we doing in studio teaching**

As Cuff (1991) notes, our current teaching methods have a relatively brief history, being little more than 150 years old. Kings College, London, for example, started teaching architecture in 1840 (Perkin, 1973). Other professions formed in the sixteenth centuries (Charlton, 1973). The aggregation of students into large groups based on age cohorts is a model developed in the late nineteenth century to cope with the need for mass education. Studio teaching appeared in architectural education around the same time as a means to teach design since it was recognised that classroom teaching was unable to succeed in the teaching of design. Since our heritage is comparatively short, it is hopefully not ossified and unable to change, since change is needed as the following discussion will show.

Schön (1987) describes the interactions of Quist, the studio master, and his student Petra and examines the nature of the exchanges between them. In this analysis, Schön highlights us the distinction between teaching explicit knowledge and inculcating tacit knowledge — the experience of "knowing-in-action" (Schön, 1987, p. 25). Tacit knowledge constitutes an important part of architectural knowledge and the teaching of design relies heavily upon developing the skills and knowledge comprising this tacit knowledge.

Schön identifies also the process of "reflection-in-action" (Schön, 1987, p. 26) by which the participants explore the realms of solutions by carrying out the process of design, shaping the outcomes through reflection on the process as it is executed. He calls this "a conversation with the situation." Schön's use of the term 'situation' leads readers to perceiving design as a situated activity (e.g. Gero, 1998).

That design is situated is widely held, if not as explicitly framed as in Gero (1998) as discussed in Section 2.5.2. Cuff (1991), for example, presents design as a choice as between decision making and sense making. She sets up a contrast between problem solving of ordered, defined problems and the understanding that design is a messy process which encounters ambiguous and conflicting demands. She then states that "the notion of sense making implies a collective context in which we must make sense of a situation, inherently social, interpret it and make sense with others through conversation and action in order to reach agreements." (Cuff, 1991, p. 254).

In this analysis, we see Cuff draw the conclusion that "sense making" is collaborative in contradistinction to rational decision making which she implies is individual. This is a curious and unsupported conclusion. She then goes on to infer that collaborative designing is situated without considering that collaborative working can also be based on other modes of cognitive behaviour. The jump from denying the decision making model to accepting the situated model instead is one which has been made by others, as discussed in Section 2.5.2 above. Cuff's



statement that design is ambiguous and conflicting is very close to Rittel's definition of wicked problems (Rittel, 1972; Rittel & Webber, 1973). As Goel & Pirolli (1992) have shown, other models than situated action can be postulated to solve wicked problems. The cognitive model of collaboration (Section 2.5.3, amended by the experimental results in Chapter 5) sets out a model by which we can understand how collaboration occurs. The role of expertise of the participants is understood to be important in the success of a collaborative activity. In teaching we must therefore focus on developing the expertise of the students, not just setting up a situation within which design occurs.

As we teach in the design studio, therefore, we transfer and establish knowledge through several means. We engage the students in discourse about their design intentions and decisions so far. Exploring their ideas, the teacher helps them to unravel their intentions from decisions that are thwarting those intentions. Using words and drawings, we explore the implications of decisions and demonstrate alternative means of achieving various ends. In these interactions, we are showing the students how we reflect-in-action and we display some of the tacit knowledge which is essential not only to architecture, but to all teaching and learning.

In addition to the transfer of knowledge specifically related to the problem at hand, the studio master is participating in the socialisation of the student into the broader web of knowledge which form the ways and concerns of the profession as discussed in Section 2.5.1. In that section, we identified three aspects of the social nature of design activity — social knowledge, social roles and the socialisation of

the participants. Design studios are a forum in which these three are introduced to the students. The students come to understand that they are a node in a network of broadly-based knowledge (Latour, 1987), including professionals such as other architects, engineers and consultants, as well as non-design professionals, such as clients, bankers, users, etc. The design studio also introduces the student to the social roles (Harré, 1993) which are represented in a typical design process, either through guests who represent such roles, site visits or through role playing by the students or studio master. Socialisation occurs as students see professionals, such as guests or studio master, carrying out their roles.

While accomplishing all these goals, how do we actually teach design? Schön identifies two primary modes of instruction: telling and listening (the studio master talks about what he is doing, the students listen); demonstrating and imitating (the studio master draws, the student draws). These can be applied separately or in a combination of both telling/listening and demonstrating/imitating. Schön then identifies the ways in which learning can be impeded. He identifies two major impediments, stance and behaviour. The problems of stance arise when the studio master tries to protect his own special artistry by failing to convey the appropriate knowledge. Alternatively, it can arise from problems of intersubjectivity, a failure on the part of either student or studio master to engage in a willing suspension of belief in the course of the exchange (Vaitkus, 1991), willing to go along without knowing the outcomes. Problems of behaviour arise when there is a failure to engage in grounding (Clark & Brennan, 1991), clarifying

the conversation as it progresses. Either of these problems will lead to a situation in which there is a perception of antagonism in which the studio master is seen to be attacking the students through their design. The role of intersubjectivity and grounding in design have been explored in Chapters 2 and 4 above.

Eraut (1994) draws our attention to the fact that time and speed play an important role in professional work and the way in which our response must vary according to the speed of interaction (see Table 2, page 112 of this thesis). The typical professional moves quickly from task to task, event to event. As we are called upon to act, we often do not have time to reflect. Issues of speed also come to play in studio teaching, either as the studio master reacts without explaining or because of the growing queue of students waiting to be seen. Thus Schön's reflection-in-action paradigm cannot explain the way we are working in situations of immediacy since there is no reflection, just action.

Deliberation, when it can occur, typically happens outside the context of action. Yet this deliberation is important to professional work. Knowledge gains meaning through its application, that is, we learn through doing. Theories are not applied without interpretation to either the situation or the person implementing the action. While engaged in actions, we do not have time to examine the implications of theoretical knowledge but accomplish this in times of deliberation after the time for action has passed. He suggests that deliberative acts such as planning, problem solving, analysing, evaluating and decision making, lie at the heart of professional work and that Schön's selective presentation of design is incomplete



and hence misleading (Eraut, 1994). In our loose coupled model of collaboration (Figure 4), this could be interpreted to mean that some steps are reflective and others deliberative, while yet others are routinised unreflective action.

Through the choice of topics and avoidance of others, through the approaches to discussion and dismissal of others, the studio master is introducing the student into both the explicit and the tacit conventions of the architectural profession itself. Through these choices and through the activities of studio teaching, the student is introduced to concepts of social roles, or social knowledge and is socialised into the profession of architecture. Most importantly, we are developing the expertise of the students in fields relevant to their professional practice.

### **6.3.2 Teaching collaborative design**

In researching the profession of architecture, Cuff (1991) found that the idea of the "preeminence of the free practitioner is inculcated through various channels... Within the schools, the core belief in individualism over collaboration is bred in the studio." (p. 251). This is even true in my institution, the University of Hong Kong, which is located in the Chinese culture, a culture of the group not of the individual. Even though much of our teaching nominally uses group settings, it still emphasises the individual, in large part because the evaluative systems we use — examinations and grades — accommodate the individual focus better than a group focus. As Cuff argues, we need to develop an understanding of collaboration as much as we need the students to understand the technical issues of architecture.

Cuff proposes that all architectural education, not just design studios, be changed to better prepare students for collaboration. She recommends that studio problems be modified to require collaboration and that juries be augmented with client representatives and consultants so that the student realises that they are required to practice within a context of others. She suggests that changes be made in other courses, such as the history curriculum, to reinforce the view that the great architects were leaders, not isolated figures. History, she suggests, should report the tales of great firms, not just individuals. The teaching of management should also turn to a collaborative focus, not just looking at the legal aspects of practice (Cuff, 1991, pp. 254-260).

Cuff's changes do not go far as they might. They are constrained by her perspective that collaborative work has to be situated in the social context of architecture. Thus her changes emphasise the introduction of people playing out various roles within the framework of traditional architectural practice. A greater emphasis can be placed on the issues of collaborative communication explicitly to introduce students to the roles and techniques of successful collaboration. We can find an illustration of how this might be done with a small exercise in Sonnenwald (1996). In reviewing the implications of her research for education, she identifies that students should be taught to communicate but not only with colleagues, using a special language of the discipline, but beyond. She calls this a course in 'boundary spanning communication'. In groups of four, her students are given a task in to build something using Lego bricks. During this 15 minute exercise, they

are forbidden to speak. This exercise, she reports, "is a powerful way to introduce them to the importance of communication in design." (p298).

We can go further and use the specific features of technology for computer-supported collaborative work. In order to understand the opportunities, however, let us first examine the different dimensions of traditional studio teaching. As will be shown, there are several aspects of studio teaching which can be changed to gain the benefits not obtained by traditional group settings, as set out in the review of CSCW systems in Chapter 3.

CSCW systems structure group processes and decision making. Recalling the five stages of the PBL process as set out by Koschmann, et al. (1994), we remember that learning takes place in five stages: problem formulation, self-directed learning, problem re-examination, abstraction and reflection, with the first three linked by circular loops permitting repetition of the stage. As noted earlier, architectural students follow this process when they engage design problems. Koschmann, et al. describes two additional stages which are missing from Schön's (1985) model for architectural education, namely the stages of abstraction and reflection. As described by Koschmann, et al, students are required in the abstraction stage

"to articulate the knowledge they have acquired, and the case is reexamined in the context of other cases the group has seen – to discern generalizations where possible, to make connections across lessons learned in different cases, and to explore similarities and differences." (Koschmann, et al., 1994, pp. 241-242)



In the reflection stage, the group discusses their own approach to the problem itself and the team reflects upon the learning process to identify areas for future improvement. This reflection stage is very much that described by Eraut as 'deliberation', avoiding the word 'reflection' since he was distinguishing the step from Schön's 'reflection' which he understands as 'meta-cognition'(Eraut, 1994, p. 149).

We can be more effective in teaching students not only how to design but also how to participate in collaborative decision making if we include the abstraction and deliberation steps in our pedagogy. The technology specifically to support design collaboration with GPSS and GDSS tools has not been implemented as no research has specifically focussed on these issues.

At this time we know little about what tools could be of benefit to design decision making. Some research is looking at decision making in design and construction with an end of building tools to support the process (e.g. Morris, Rogerson & Jared, 1998). In a medical application, for example, Koschmann, et al. (1994) describe a proposed Collaborative Learning Laboratory (CCL) which is developed from work in CSCW. This laboratory is a custom-designed suite in which students sit at computer terminals, looking at two screens. One screen is their private computer desktop on which they can arrange material as they wish, using it for note taking and preparing work as well as interacting with others. The second screen is a projected public screen that serves the role of a normal blackboard/flip chart in traditional face-to-face group PBL teaching. During a session, the tutor

(Koschmann, et al. call this person a coach to emphasise the facilitative nature of their role) asks questions to which the students respond by typing a message and sending it to the coach. This allows electronic anonymous polling of the group, gaining the benefits of anonymous participation noted in CSCW research (Gallupe & DeSanctis, 1988; Dennis, et al., 1988; Gallupe, et al., 1991). Alternatively, the responses can be attributed, allowing individual participation to be emphasised. Koschmann, et al. note that this method of interaction will only complement group discussion, not replace it. Teaching in the CCL is to be augmented with multimedia-based databases for case notes, teaching case libraries and a patient interaction simulation. A similar set of tools can be created to support design studio projects, with precedents of buildings types and construction details online.

Even without specialised GPSS and GDSS tools, we can take advantage of the virtual design studio opportunities to expose the students to collaborative decision making. Just as traditional design studio programmes can be written to investigate particular design issues, we can write design programmes which require and highlight the collaborative process. The technology can also be used to highlight and teach aspects of design which are more difficult to address without the supporting systems.

Two examples can illustrate the point: the use of bulletin boards and the use of chat lines. One goal of studio teaching is to provoke students to think and debate about critical issues in architecture. To do this we can use technology such as bulletin boards or Hypermail to post questions, discuss the issues and draw

conclusions. The class can be structured to invite or require participation by all students. Every participant can access the discussion at any time. While it is feasible to teach like this using flip charts and posting the lists to the walls, computer technology offers us greater flexibility to evolve the lists. The discussions are also richer if they include participants from different perspectives such as distinct cultures or theoretical persuasions.

While that example illustrates using technology to carry out better what we already try to do, an example can be found to illustrate the use of technology to support something we may not already do. While reflection-in-action offers the students the opportunity to observe and reflect upon the graphical and verbal actions of design, we leave no trace of the design process at the end of a session. If we wish to analyse design, we need to generate transcripts of the sessions (e.g. those used in protocol analysis such as Chapter 5 or as discussed by Purcell, et al., 1996). While not requiring students to engage in formal protocol analysis, it would be instructive for students to be able to reflect on their own design processes. Being able to read a transcript of a session would provide such an opportunity. Chat line or MOO systems can be used to conduct discussions, the resultant text stored and analysed in future reviews of design decision-making processes. A collaborative design session supported by a chat line would place the students in a situation in which the design process has to be externalised in discussion and would leave a trace of the discussion for future review. The studio master could participate in the session to encourage important issues to be



addressed, ensuring the trace is rich enough to warrant discussion. This discussion exercise will introduce the students to the concept of deliberation (Eraut, 1994) which is at present not emphasised in the reflection-in-action model of design teaching.

As these examples show, the introduction of the technology offers opportunities to change the way studios are run to explore new pedagogical aspects of design teaching. Design programmes will need to be re-written to emphasise the issues which can best be illuminated by CSCD. In particular, the tasks will need to require real collaboration. This is a challenge which can be addressed by either writing the brief around role playing, requiring students to assume fiduciary responsibility for different aspects of the brief, or establishing problems which draw upon different domains of knowledge, such as the second condition of the experiment in Chapter 5. The goal of the programmes needs to be developing the knowledge and expertise in the collaborative process while developing architectural expertise as well.

## **6.4 Settings for design teaching**

A typical cycle of design teaching takes the student through a number of settings. First, the design problem is introduced. Students and teacher gather to discuss the specifics of the problem set (size, site, building type) and the intentions for the studio itself — what is to be investigated in particular (structures, construction, social issues, etc.) We also review the constraints — time, resources, outcomes.

At this point, the student has a chance to ask questions and then retires to digest the information conveyed. This maps on to the problem formulation stage in the PBL methodology (Koschmann, et al., 1994).

After the brief is introduced, further interactions occur in both formal and informal settings. Formally, the schedule will call for design presentations at which the student has to "declare their hand", committing themselves to a position consisting of a formulation of the problem, an approach to solving the problem and a solution itself. These presentations typically consist not only of the final presentation (a final jury) but also interim juries from which the student will receive formal criticism of their project.

Informal settings will consist of desk crits — reviews held at the desk or the student or at another desk to which the students bring their work. The material brought to these desk crits is typically rough, often multiple in intent and unresolved in outcome. Students participate in these desk crits in two ways — by bringing their own material to be reviewed and by observing the review of others, for often these desk crits are held in open areas which permit others to observe and perhaps to participate. Some studio masters set up peer juries to encourage participation as there is much to learn from observing another's review (Anthony, 1991).

At all of these reviews, the students are free to use a range of materials. Some studio problems may be formulated to require or predispose the student to

investigate particular media; for example, a studio may be based on the notion that sculpture can be used as a medium for design investigation. Others may allow the students to use whatever media they wish. Regardless of the media suggested, students will employ a variety of media both as resources and media for exploration. Books, video, photographs, models, sketches and even real life typically contribute to any design evolution.

#### **6.4.1 Settings for a VDS**

Virtual studios occur in a number of formats, with the only common feature being that some of the participants are remotely located from others. Thus, in one permutation, we link up students in one university with those in another, each location having a complete complement of participants (teachers and students) but the problem posed requires the participation of both sites to satisfy the studio objective. In another permutation, the teacher is remote from the students, perhaps because the students or the teacher are working from home or office and travelling to the campus infrequently. This permutation finds its ultimate expression in the setting of Distance Learning where the students are unable to attend classes at the campus without great difficulty in travelling.

In professional training which takes place in an accredited school of architecture, the basic communications are still required in all of these permutations. A studio master is required to guide and supervise the studio. A program has to be issued, a design problem stated. Students are then to explore and evolve ideas and propose solutions. Reviews are needed along the way, with tutor reviewing student



submissions. If this were not an accredited school, we might include auto-didactic experiences in which some of the communication can be done away with. That model, however, lies outside the scope of this discussion.



**Figure 24:** A student in a teaching studio at the University of Hong Kong

For VDS which are conducted within the context of a traditional school of architecture, we should consider the relationship of the studio to the other courses and settings. The examples of VDS reported in Section 3.4 all were conducted completely within a digital environment. It is not necessary that the VDS be conducted only online; it can draw upon the other contexts which we normally use in traditional studio teaching — lectures, seminars and site visits. The group can conduct site visits via either live video cameras onsite (Savage, 1996; "ZGFNet", 1997) or web pages documenting and perhaps animating site case study conditions. Seminars can be conducted together, either through live video feed (Grant, 1997), a difficult and potentially expensive experience, or through online



discussions conducted through bulletin boards or other computer-mediated communication systems.

Most obviously, communication modes change. Sitting adjacent to a tutor, listening to their comments as they work, the students observe the acts of knowing-in-action and reflection-in-action which Schön identifies. This interaction is enhanced by all the benefits of face-to-face presence such as appearance, facial expression, posture, gaze which influence and direct conversation. How can this be achieved when the bandwidth is substantially less than that available when teacher and student are collocated?

Using our earlier analysis, we can see that the tutor must address these changes by considering both the technology and the procedures of teaching. As can be seen in the reported VDS experiences to date, a common technique is to try to recreate the face-to-face setting by relying on communications technology to establish a maximum facsimile of immediacy, using video and audio systems to convey presence. As discussed in Chapter 3, the expected benefits will prove to be elusive.

In a review of teaching Open University students remotely using the telephone as the means of communication, Short (1974) notes the functions of visual information in teaching: feedback, information about interpersonal attitudes and visual aids to teaching. He identifies the practical implications of non-visual communication in teaching as an increase in impersonal behaviours, hindrances in

conversational structure, and a difficulty in identifying the social structure of the group. While he concludes that although there are substantial benefits of using the telephone to teach when physical presence is not possible, such as the ability to deliver teaching to students who would not be able to access it otherwise, it is definitely inferior to face-to-face.

Short's observations are usefully supplemented by the experiences of a tutor in a French language and literature tutor in an Open University course (L'Henry-Evans, 1974). L'Henry-Evans observes that the technology requires 'intense concentration' by the tutor. She was teaching a face-to-face tutorial with another group of students in parallel and found that she was able to reflect on the different interactions of both groups in order to improve the processes in both cases.

When the modes change, new techniques will need to be found to achieve appropriate ends (which may be different from those in the face-to-face condition. For example, L'Henry-Evans employed some specific techniques to overcome the perceived problems.

- She contacted each student individually before starting group sessions, thereby establishing the individual presence of each, overcoming the problems of anonymity.
- Each session started with introductions by every student so everyone knew who was present.



- Proper discipline was essential to ensure everyone had equal opportunity to participate. She used alphabetical sequences by name to bring everyone in at each stage.

There is a similarity between her techniques to ensure participation and inclusion in the group work and those techniques used by facilitators when working with partnering in projects (Allbriton & Smith, 1996), namely the identification of the participants, an opportunity to establish their personal voices and the monitoring of group process to ensure participation.

Most importantly the teacher must remember that the new conditions present new opportunities. It may not be enough to try to reach the same ends as when teaching face-to-face. L'Henry-Evans' approach, for example, rules out obtaining any of the benefits of anonymity and social equalisation reported by Gallupe, et al. (1991).

Remembering that much of our teaching is public, conducted in open studio settings where others can listen in on the conversation and hence learn by observing another's design critique, we should try to keep remote sessions open to achieve the same benefits. One of the difficulties in teaching a studio group is to ensure participation by all students. During group sessions the more articulate may tend to hold the floor and prevent others from speaking. A student who exhibits a familiarity with the language of design may intimidate others contributing their thoughts. Anonymous postings to an asynchronous bulletin board could address both problems. Similarly anonymous postings of drawings in

response to a design exercise could open the studio to design reviews without the problems of favour being raised by combining the two techniques, anonymous drawings and comments

## 6.5 The teaching compact

In reviewing the process of a design studio we should not concentrate on the explicit actions within the studio and forget the implicit agreements, the compact, which bring the teachers and students together. The compact is built upon the motivations which drive the students to participate. Students wish to gain the status, and perhaps the concomitant rewards, accorded to professionals in most societies. In order to gain that status, the students need to obtain the knowledge which is the domain of their profession (Kuhn, 1970; Latour, 1987).

The teaching compact in a professional course extends to society itself. Professionals are accountable to the society within which they have been accredited. The professions must continually legitimate the knowledge base which is their authority (Eraut, 1994, p. 223). In exchange, society allows the profession to assume the power of self-regulation by which current members of the profession decide who may be admitted as future members (Rueschemeyer, 1983, p. 41). The teaching compact therefore exists with the profession, as expressed by the regular accreditation reviews. The school of architecture agrees to maintain the knowledge base and to support the professions compact with society (Eraut, 1994, pp. 6-10).

Each participant in the studio has expectations of the studio experience and of the others in the studio. The tutor expects the students to apply themselves to the task set, to engage the problem in an intellectually effective manner and not to shy away from exploration. The students have expectations of the teacher. For example, at the start of the semester or term, the students may wish to expect that the teacher will illuminate the problems, perhaps to be a fair and attentive sounding board for ideas and facilitate the process of exploration of problems which crop up. Some students may expect the teacher to dictate the outcomes, guide them to the solution or to set the boundaries within which exploration will take place. Each of these expectations may be accommodated to varying degrees depending upon the goal of the studio and the capacity of the teacher.

As the studio progresses, the students will need to make an effort to remain interested and motivated. What motivates a student through the course of a design studio? As the term progresses and the design problem appears to get more difficult or complex, the students experience different motivations to continue pursuing solutions. Some students are highly motivated by a need to complete, to find the shortest path to the end; others find themselves engaged in an intellectual quest which risks diverging from the intent of the studio; yet others are motivated by the activity of others, a peer pressure or peer competitiveness. As every studio teacher knows, some lose all motivation and have to be redirected or their enthusiasm revitalised. Of course, there is always an underlying need to satisfy the examiner which motivates many students; this motivation cannot be ignored as



it colours and constrains the thinking of students, albeit to different degrees, encouraging them to try to second-guess the examiner.

A studio teacher needs to be aware of such variations in student's motivations as they influence and constrain the range of explorations undertaken. Over concern about examiners hobbles exploration, encouraging safe thinking; peer pressures encourages conformance; personal explorations can lead to remote dead-ends. A teacher is always looking to see which direction the students are heading, bolstering the enthusiasm for exploration but encouraging productive exploration of possibilities.

### **6.5.1 Teaching compact in a VDS**

The essential compact between teacher and student does not change when the teaching is carried out remotely. An additional obligation is assumed by the teacher, however, as the need for facilitation in the teaching is greater. Not only does the teacher need to guide and encourage the students, they must also help the students master a new medium, a medium which is currently unreliable, difficult and cumbersome. The facilitation role then takes on a much larger importance than in the traditional setting.

There is a corollary obligation which cannot be ignored. The VDS setting imposes a greater responsibility on the student to control their work. Communication between the teacher and the student has to be more structured than the more casual interaction which can occur when face-to-face. For example, seeing

discarded alternatives which lie nearby when carrying out a desk crit, the teacher can draw this additional work into the discussion and illuminate the discussion with the student's own effort. In online communication, the student has more consciously to present work for review, thus assuming an significant editorial role in the communication even during the desk crit phase and not only in the formal reviews.

Some students may find it difficult to adjust to regarding the teacher in a light other than leader and instructor. This problem has been noted from experiences in PBL (Russell, Creedy & Davis, 1994).

When engaging a student in a virtual studio, the tutor has additional obligations imposed by the distal setting. Firstly the tutor must recognise the problems inherent in the communication medium and set up a working style which overcomes the remoteness from the student. Students often seek immediacy in a reaction, they wish to know if their tentatively offered idea meets with acceptance, or they wish to have a statement reinforced before offering up the next idea. Face-to-face, we encourage progress and we guide by numerous non-verbal interventions in a conversation. Online, these non-verbal clues need to be replaced by some other conventions, such as rapid responses indicating acceptance of a statement or notations on a shared whiteboard drawing indicating that notice has been taken. This is especially difficult in asynchronous exchanges.

Additional assistance has also to be given as the students struggle with the difficulties of the digital medium. At this early stage of the technology, there are few trails to follow and the students are faced not only with grasping technical and architectural issues but also process issues, especially those of communication and collaboration.

This difficulty is an opportunity for the changing compact. As noted earlier in this chapter, a virtual design studio offers an opportunity to address the issues of collaboration more explicitly. Collaborative skills are important to the professional but ignored in most professional training. The studio master therefore has an opportunity to bring students into a greater understanding of collaborative processes. As such, the virtual studio is richer than a collocated studio and offers greater potential to explore some of the fundamental questions of the professional compact.

## **6.6 The studio master's contribution**

The studio master is present in the design studio to provide two essential contributions. In Schön's terms, the studio master is there to demonstrate the knowledge-in-action and to introduce the student to the process of reflection-in-action, as well as to inculcate the values and processes of the profession. Additionally, the studio master contributes a structure to the course, provides impetus to proceed and guides the student away from excessively problematic



directions but permitting more manageable problems to arise as it is through them that the student learns.

The format of studio teaching permits a variety of interactions and methods to be employed. Some studio masters direct, pronouncing on the degree to which a solution belongs to a set of permissible solutions. Other studio masters will engage in Socratic dialogue with the students, opening up opportunities for discussion, bringing the students in to the exploration of a solution, much as illustrated by Quist in Schön's documentation of such sessions. As noted above, the studio master is also introducing the student to the social aspects of architecture, socialising the student to a professional perspective, identifying the social roles of the participants and establishing a social knowledge in which the student can participate.

Exchanges that do not take place face-to-face have a higher incidence of misinterpretation than those that are laboured over face-to-face. Reminded by Harré, we remember that actions gain meaning from the context within which they occur, indeed that the acts themselves obtain meaning from the larger context. It is important to convey context rather than actions — actions can be substituted but the contexts not. Much of the work on the role of video and audio in computer-supported collaboration is justified by the need to convey all actions. For example, Tang (1991) notes the importance of gestures in design communication. We suggest that these gestures are actions in Harré's sense and other actions can be substituted to the same effect. Thus, the context can be constructed from

something other than replication of co-location for professional exchanges. The challenge to the participants is to recognise the need to find alternate ways of conveying meaning and to identify the available alternate modes. From this perspective, the cheaper the communication medium (e.g. lower bandwidth) the better as more can be communicated for the same cost, although we recognise that some actions are more efficient than others at conveying meaning. That is what the results of the experiments in Chapter 5 suggest.

As Nunamaker, et al. (1995) have found, agendas and structure help electronic meeting systems run smoother than face-to-face events, formalising some aspects of social roles and socialisation. This suggest that we should pay greater attention to methods of expressing goals and roles through structures and processes rather than relying on technology to convey maximum information on the chance it might help. We have already noted in Chapter 2 that design collaboration takes many forms, synchronous, asynchronous and semi-synchronous. It is therefore inappropriate to assume that synchronous communication is necessary for collaboration.

Certainly some problems are introduced by computer-supported collaboration. 'Environmental' factors (physical, temporal, cultural) should also be considered. Collaboration with distant colleagues introduces problems not experienced when collocated. If you are pulling the others out of bed at two in the morning, you can expect them to react somewhat differently than a colleague sitting on the other side of the table sharing the same time zone as yourself. But opportunities also

arise. For example, social roles are more difficult to define when the persons are unknown, but the lack of prior definitions can make the quality of communication better (Sproull & Kiesler, 1991), preventing established social conventions from becoming barriers to communication. Similarly, a digital context allows the participants to capture social knowledge as it arises and to render it more readily accessible in digital form.

The student too makes a significant contribution to the design studio beyond the mere generation of output. Although the studio master and the school timetable dictate the overall time frame for a project, the student is in control of the pace of their learning to a far greater extent than in a lecture or classroom format. Time spent at various points along the way, the effort allocated to investigations at each moment is very much decided by the student.

### **6.6.1 The studio master's contribution to a VDS**

As noted above, the studio master in a design studio introduces the student to the realms of tacit knowledge which cannot be accessed through book learning. By working alongside a student, the tutor demonstrates the processes of exploration and solution finding Schön calls knowing-in-action and reflection-in-action. At the same time, the students come to understand the implicit social compacts within the profession.

It may be that the teacher should not lead the group — if we wish the students to learn to collaborate, they need to learn to manage collaboration. In some contexts,



therefore, the role of the tutor will change from leading to participating (McConnell, 1992).

It is important to consider too that in many VDS implementations, the teaching becomes team teaching — the studio master is no longer the sole teacher in the group. While this may appear to be the case in many colocated studios, it is typical for students to identify with only one studio teacher and to attend reviews and classes with only that person. In a VDS, it is common that there is at least one studio master at each node. The roles of these teachers can clash if they all try to take active and leading roles. Alternatively the students may feel abandoned as the teachers step back and let the student interact without sufficient participation by the teacher.

## **6.7 Peer learning**

Problem-based learning permits a wide range of learning situations to arise. Students draw upon a variety of people to assist in the learning, not only the teacher. Typically teaching is considered to be a one-to-many relationship between the teacher and the student. Peer learning recasts the setting as a many-to-many situation. As Bruffee (1993, p. 1) points out, peer and collaborative learning is "underdeveloped, underused and frequently misunderstood" which offers many benefits and opportunities not available in a one to many model. We should therefore understand it better to obtain the benefits available.

According to Kaye (1992), interest in collaborative learning rests upon six assumptions:

- That much significant learning and deep-level understanding arises from conversation, argument, debate and discussion... among and between learners
- Peer collaboration in learning can directly help to develop general problem-solving skills and strategies through the internalisation of the cognitive processes implicit in interaction and communication
- The strengths of collaborative learning through discussion and conversation include the sharing of different perspectives, the obligation to make explicit and communicate one's own knowledge
- A significant proposition of many people's jobs involves working in teams and groups... formal education should prepare people to work together in groups
- Groups of adults... often have a valuable repertoire of personal knowledge and experience to contribute to the educational process
- Outside formal educational settings... much of the individual learning that occurs results from informal group interactions... what Illich (1971)... called "learning webs" (Kaye, 1992, p. 3)

As can be seen, many of the benefits identified in this list are those which we attribute to studio teaching. The concept of 'learning webs' referred to extends the idea of 'knowledge webs' (Latour, 1987) which have been developed in Chapter 2.

Our experience in Hong Kong tells us that students succeed in learning well when they work together on a problem. Dividing up the tasks, they are able to cover more ground and examine more issues. Discussing the problem between themselves allows them to examine the issues and test ideas in a more comfortable setting. It is not an uncommon experience to find the students gathering to review and discuss the comments of the studio teacher once the latter moves on to the next desk or the next room. As Kaye (1992) notes, however, many of these

benefits are difficult to obtain and do not arise naturally but must be sought and supported.

### **6.7.1 Peer learning in the VDS**

Peer learning plays a very important role in computer-based activities. Peer learning is an important mechanism in learning computer skills — by sitting next to another, more expert, user, a student can acquire the skills necessary for executing work. This can be seen in traditional design studios to as students acquire the basic skills of drawing, model making, painting, etc.

Working with peers remotely, however, highlights a problem which does not need to be considered in a traditional studio. Vaitkus (1991) draws attention to the fiduciary responsibilities of group members. He notes that effective groups cannot be formed if anonymity is present. Thus, effective fiduciary relationships can not be established when members do not know one another. Peer learning is difficult when the group has not been established. The development of trust between participants is an important part of developing an effective VDS.

This was highlighted recently during a recent debriefing of students after a VDS. The students complained as usual about the difficulty of communicating with someone who is not in the same time zone or same place, that the channels of communication available being inadequate. When probed further, the remarks were sharpened to identify the following problems:

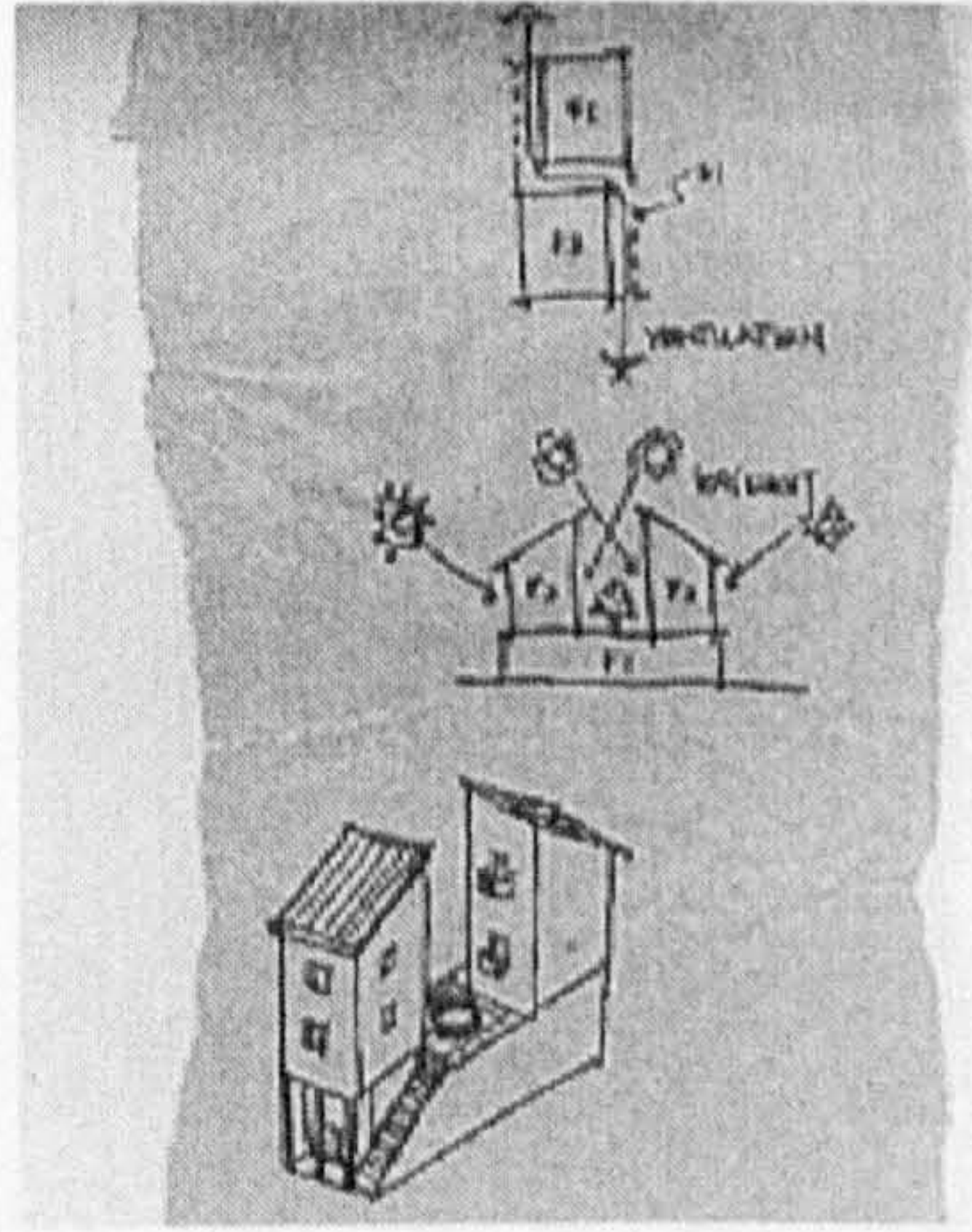


- familiarity — the difficulty of gaining any sense of the other participant and hence to gauge their reactions;
- response and reactions — difficulty getting any or knowing how to interpret;
- need to convert all communications into one digital medium.

One student crystallised the issue when she identified the role of trust in the success of her work. Once she and her remote partner had established a level of trust in their communications, the two participants were able to comment with confidence on the other's work. The trust permitted a true collaboration to develop such that the resulting design was not clearly one person's or the others. In Vaitkus' terms, they were able to work together by reaching the level of "simply submitting and giving oneself over" to the process and their partner (Vaitkus, 1991). At this point, they achieve the necessary condition that Cuff identified for successful design interaction where "the design process is characterised by warm, almost familiar relations among the actors, as well as conflict and, at times, tension." (Cuff, 1991). What is of interest in this instance is that the VDS was held without any video or audio connections. The student noted that they were able without difficulty to establish the familiarity to which Cuff refers through e-mail and chat line exchanges, supplemented by attachments of images either scanned or digitally drawn. A sufficient understanding was gained by the identification of issues of mutual interest and individual perspectives through these synchronous and asynchronous communications. Some users of computer-mediated communication in teaching have noted that the students regarded the digital



medium for communication as very effective (Søby, 1992) as it broadened the experience and introduced an equality they did not achieve face-to-face.



**Figure 25:** A scanned sketch for transmission

## 6.8 Knowledge resources

In the process of exploring design solutions, students reach outside the immediate confines of a design studio and draw on other resources. In a University setting, the extensive multidisciplinary library is always used. Non-academic materials, such as product catalogues, professional magazines, etc. are often found in a departmental collection such as a reference bureau. Local practices, the construction industry, material suppliers and the alumni also offer resources to be used by students, both during design explorations and also in the review process and juries. While these are important resources during a student's design effort, the student is also learning about their existence and accessing them is an important learning component itself.



### 6.8.1 Resources in a VDS

The Internet is a tremendous source of information but this is not unique to a VDS. You can take advantage of the same resources in a traditional studio setting. What is different in a VDS is that the student's work is accessible on the network and potentially accessible therefore by remote advisors. Thus, the student is no longer constrained by the proximity of practitioners or consultants but can ask remotely located experts to offer advice. In this way, the Internet is directly expanding the network of knowledge to which Latour (1987) refers. Some schools of architecture are already taking advantage of this by inviting experts to provide desk crits remotely as the design studio progresses. Students are able to search for their own sources of contribution as well, much as they may do by visiting a local supplier of building materials or technology to answer particular technical questions about their design.

Technologies of web presentation are evolving rapidly and offering new means by which to present architectural work. A VDS is a good environment in which to address these new techniques, ones which the students must become familiar as they are also being used in practice (Savage, 1996; Phair & Angelo, 1997; Ross, 1997).

At the University of Hong Kong we have used the technology to go further and develop an online library of student research which remains accessible from one year to the next for reference. Students in the second year of the five year course are required to carry out analysis of precedents in a building type. In groups, they



gather materials and prepare presentations on structural systems, services, design concepts and construction methods for these precedents. The presentations are packaged in HTML format and the groups present their findings to their peers. The design studio project immediately following this exercise is set within the building type they have analysed. These web pages become an online resource for the whole class. Working within a virtual world permits the student to build links to these resources and, in this way, integrate them into their work in a more intimate manner than a physical resource can be integrated. Thus the VDS setting invites the student to reconsider the meaning of external sources of knowledge and their presentation.

## **6.9 Reviews and juries**

The design teaching process culminates with the design jury at which time the student is expected to present their work for discussion by critics. Typically the jury is open to all to observe and the student stands before a sea of faces, familiar and unfamiliar. The student is typically given some time to speak to their work, explaining it to the critics present. The critics then have the floor and engage the student in discussion, questioning aspects of the work, then summarising an opinion. Often the jury continues into a debate among the critics in which different perspectives on architecture, leading students to learn that there are multiple acceptable perspectives.

Design juries have been an integral part of design education from the outset (see Anthony (1991) for a thorough review of design juries). As Anthony notes, the open juries that we know today are relatively recent phenomena, having evolved from closed juries in the past 50 years. These closed juries were held without students, the critics judging the work purely on the merits displayed on the submitted media itself. Such closed juries are, of course, still the norm in professional competitions.

Juries prepare the students for later practice by developing in them the skills of presentation and argument. They learn to organise their thoughts so convince an audience of the merits of their design proposal through articulation of ideas both graphically and verbally. Thus the jury is an essential part of the design studio education.

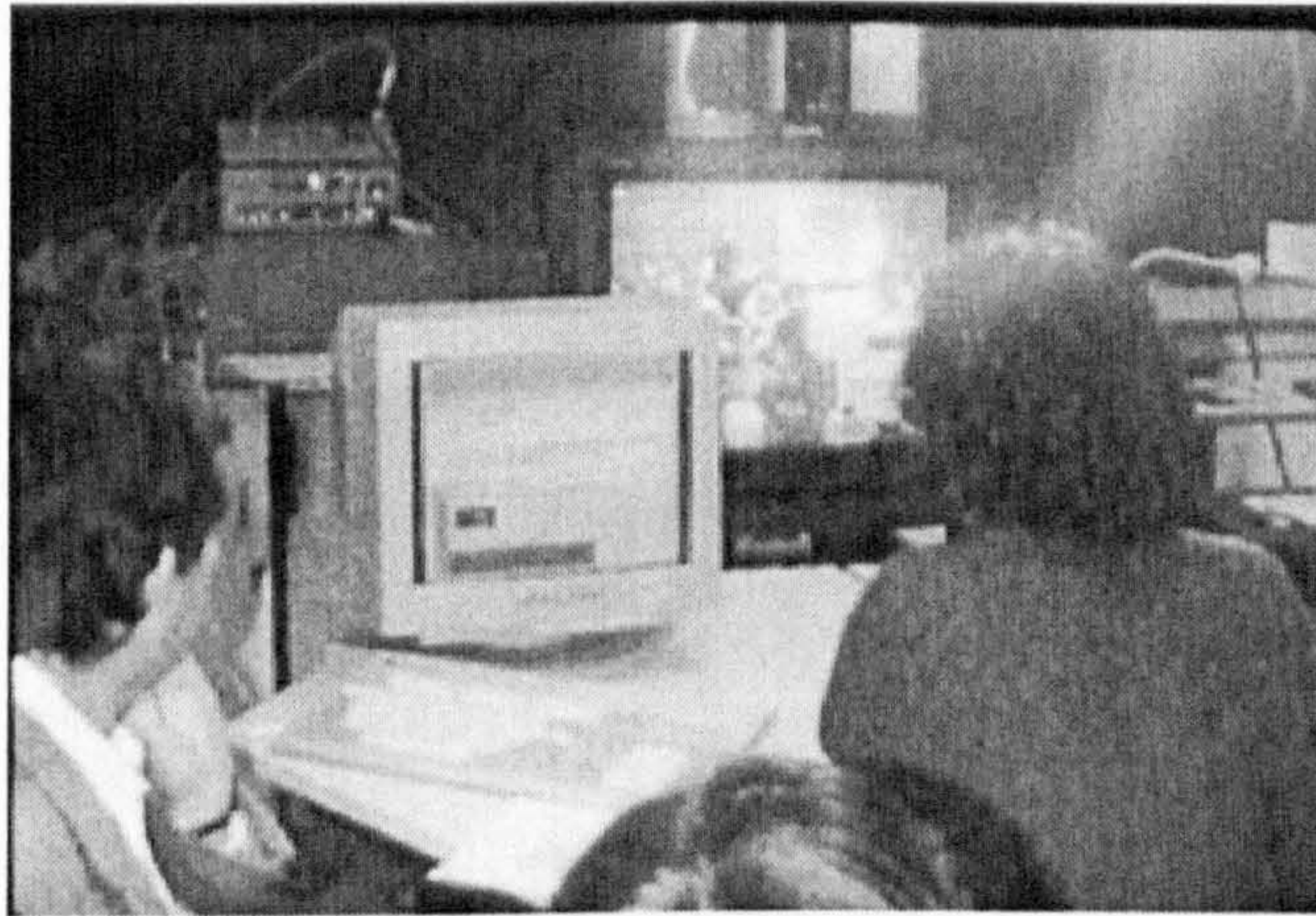
### **6.9.1 Virtual Reviews**

Virtual reviews fulfil the same role as face-to-face juries. Presenting in a digital environment, the students are required to articulate their designs so as to communicate to critics the value of their ideas. In this new environment, however, they have to learn a new set of communication skills (Kurland & Barber, 1996).

The bandwidth problems encountered with current communications technology and channels challenges those organising virtual design studios to reconsider the requirements of a design review. Adopting the conventions of traditional jury presentations requires the solution of numerous inadequacies of computer-based



video and audio transmissions. Several VDS experiments have attempted to replicate open juries. For example, Sheldon, et al. (1995) describe the difficulties encountered in setting up such reviews. They note too that the problems are not only technological but also "social and cultural interactive communication challenges" also work against such juries at this time.



**Figure 26:** A virtual review using video link

Other schools (such as the University of Miami) have attempted to avoid the problems of synchronous juries by arranging MOOs and MUDs where participants can review the material on-line and leave comments as they are able. Here the problems of bandwidth are minimised for the communication although participants notice that bandwidth still makes it very difficult to download work sufficiently rapidly to review a large quantity of work.

One aspect of the review process which has not received much attention is the need for the student to package the work in a way which is more sympathetic to on-line review. Most students participating in a VDS attempt to prepare elaborate



and complex images which can only be understood when viewed concurrently with other images, for example, a rendering and a plan. In a VDS review, it is typical to have only one image available at a time. Thus, the VDS raises questions about presentation itself which are part of the learning during the studio, making the process itself more important again than in a traditional studio where the conventions are well established.

Students report learning more from desk crits than from final juries (Anthony, 1991, p. 35). Desk crits are easier to establish within a VDS than large collective open juries. Perhaps a VDS should focus less on final juries and expand the desk crit relationship to encompass the final presentation. Perhaps MOOs would be less intimidating for reviews than live presentations. While network-based presentations are beginning to be used, it is a fact of our professional lives that we must present to clients face-to-face sometimes so the training of juries is useful. Chiu (1995) reports an online review where jurors were able to copy images from student presentations and annotate or redraw them to illustrate their point. While that is possible but destructive in traditional juries, the new medium permits this degree of more direct interaction between critic and presenter.

## 6.10 Discussion

While the exigencies of practice make it difficult to avoid engage in projects in which team members are located in another office or another town, this is not the case for a teaching studio. There is no requirement to team up with another school

and teach a joint studio. The choice to engage in distal collaborative design in a teaching context is one made of free choice. It must therefore be made with the expectation that a Virtual Design Studio an effective or necessary means of teaching design? Several who have tried it have concluded it is not. The technology is not cheap to acquire and is occasionally difficult to support. The problems of communicating over a computer network appear to multiply geometrically based on the number of participants — a large class can therefore be very difficult to support. At a time when many universities are reducing funding, how can we justify spending money on such experiences?

There are strong educational reasons. The teaching context at the University of Hong Kong may be a good example to use, illustrating many of the problems encountered in many other universities, not least in China. We teach students who have limited financial resources. They are unable to travel easily, usually waiting until they have earned some money of their own after graduating. These students therefore have limited experience of the world and other cultures. This is a significant problem in our educational process. Most of the example of architecture we use come from abroad and must be understood within the cultural and social contexts of these other places. It is difficult to give our students adequate exposure to these other cultures without travel, but a vicarious exposure to other cultures through interactions with students from overseas is a help.

While journals offer some means of exploration, the immediacy of contact with students and teachers from abroad is substantially better. With this contact come

challenges which force the students from assuming their perspective is the only one. The contact is a more active engagement than the act of reading. If the exchanges with students overseas are good, the participants do engage in discussions of substantial issues about culture, architecture and different perspectives on the world.

Furthermore, as practices use computers for more communication, our students must be properly prepared. As part of our training, therefore, we need to expose students to the technologies and give them the opportunity to master the skills of communication in this new medium, just as we encourage them to develop appropriate skills of communication through drawing, model making, and jury presentations, among others. This training in itself will stand them in good stead as no-one will be able to work in an architectural practice of any consequence without encountering computers. Clients are demanding the development of digital data for subsequent building management use. Governments are beginning to require permit approval drawings in digital form. Consultants expect to share digital backgrounds on which to develop their specialist drawings.

Most importantly, though, the medium offers students a chance to learn something we do not address at the moment. Design education today fails to address the collaborative nature of the student's future professional work. Unlike face-to-face teamwork, digital collaborative exercises can leave a trace of the activities which occurred in the course of the studio. This offers a unique opportunity for us to use this material to help student learn what happens during design, to look back at the



course of events and learn from their actions. Studios offer students an opportunity to explore, test and fail. Too often we do not have time to digest our experience, especially the failures, not least because the documentation of our events is poor. With the understanding and full knowledge of the participants it is possible to collect extensive data in the course of a VDS and then use this as the basis of further learning. With this we can give students guidance on how to deliberate on their mistakes. Perhaps this process could supplement the jury review of the end product with a review of process, enabling students to obtain more than the little they seem to derive from most juries (Anthony, 1991).

The advent of the virtual design studios appears to raise promising opportunities for reconsidering the way we teach design. It changes the relationship between teacher and student, and student and the rest of the world. In this way, it opens up numerous opportunities. The attitude to design teaching expounded by Schön underlies most design teaching today (Schön, 1985). We teach through demonstrating action, reflection in action and knowing in action (Schön, 1987, pp. 25-26). If, however, design is deliberative and not only reflective (Eraut, 1994), the process of doing is less important than the cumulative acts of doing, the precise nature of which are less important than their experience. In collaboration the role of expertise increases. A VDS offers the opportunity to change the focus and address both aspects, for example as illustrated by changing design teaching to include the abstraction and reflection stages of the learning process as described by Koschmann, et al. (1994).

Decisions about the configuration and implementation of a virtual design studio cannot be made on purely technical considerations. We have an opportunity and obligation to reconsider the teaching methods we employ and adapt them to these opportunities, rather than forcing the new process into our recently adopted conceptions about appropriate ways to teach in a design studio. As noted at the beginning of this chapter, a full consideration of all these potentials is a substantial undertaking and beyond the scope of this thesis.

A consequence of this shift to an emphasis of experiential learning has directed professional architectural training to rely more and more on the reflection-in-action perspective. The education of architects today is embedded more and more in the activity of the studio with a divide between courses taught outside the studio (seen as 'theory') and those within (seen as 'practice'). Studio teaching remaining in the minds of most faculty and students as being the more important. This divide has also led us to de-emphasising theoretical understanding of the practice of architecture and design. As Eraut notes:

Thirty years ago, professional expertise tended to be identified with propositional knowledge and a high theoretical content, regardless of whether such knowledge ever got used in practice. (Today) most theories of expertise... appear to have assumed that expertise is based mainly on experience with further development of theoretical knowledge having almost ceased soon after qualification. (Eraut, 1994, p. 157)

Nowhere do we find this more obvious than in the teaching of computer-related topics. In almost all schools the teaching of computer-aided design is subjected to tremendous pressures to stick to skill acquisition. Direct training in the use of a particular CAD system is preferred by teachers, students and the profession to a

developing a theoretical understanding of the tools. Why is this happening? Why are we under such pressures? Eraut suggests reasons for this attitude.

Why has the pendulum swung so far in the other direction? Several explanations come to mind. One is the strong anti-intellectualization of the 1980s exacerbated by the exaggerated claims of the immediate post-war era. Another is the failure to properly recognize theory in use, a point strongly emphasized by Argyris and Schön (1974). A third, I could argue is the failure to recognize how theory gets used in practice, that it rarely gets just taken off the shelf and applied without undergoing some transformation. (Eraut, 1994, p. 157)

The exclusion of theory at the expense of action has also been encountered by those using problem based learning as a model of teaching. 1994 (Ostwald & Chen) report that the course at the University of Newcastle School of Architecture, the longest running application of PBL in architectural education in Australia, has been criticised by the professional body for marginalising theoretical issues. The students and the courses tend to emphasise realism over theory, tying the students to the mundane details of practice. Obviously this problem has to be considered before embarking on the implementation of a virtual studio.

Since collaboration over networks throws us into a fundamentally different relationship with participants than face-to-face, we should use the opportunity to reconsider what we teach in such a setting. The processes for studio teaching as identified in Schön (1985) are "telling and listening" (p. 65), "demonstration and imitation" (p. 71), with both methods combining to achieve the goal of moving a student up a "ladder of reflection" (p. 75). In this ladder, the studio master moves a student from the basic level of reflecting the substance of the design, through to



reflecting on the action of designing up to reflecting on the meaning of the actions or words (Schön, 1985), that is, from action through to meta-cognition (Eraut, 1994).

The emphasis on reflection-in-action present in studio teaching encourages the participants to remain at the level of the first or second rung of the ladder. In changing the context to a virtual studio, we have the opportunity to emphasise the third rung through what Eraut calls deliberation. Rather than simply trying to replicate the face-to-face context, we may be able to achieve our teaching goals more effectively by changing the context. By configuring the technology of a virtual studio in different ways, we can emphasise different aspects of design experience. Hayes (1985) notes that the most important understanding to impart to students is that problem solving skills including such as composing and designing take many years to achieve, many more than the number of years spent formally in a school of architecture. By introducing the abstracting and reflecting stages of the PBL model, we can bring Eraut's deliberative understanding of architecture together with Schön's knowing-in-action model, opening for the students a more profound understanding of design, collaborative and individual.

While change to the way we teach design is possible, we should recognise that schools of architecture are professional schools, subject to review and accreditation by the profession. This places constraints on our teaching methods. Often advances in teaching are constrained by the inability of the profession to keep up. Changes in the professional application of computers will need to

parallel with the integration of computer-mediated collaboration into the teaching of architecture. While the conditions remain not conducive to accumulation and development of theoretical knowledge, as Eraut notes, schools will find it difficult to make such a shift.

## 6.11 Conclusion

In this section we have brought together the theoretical grounding for computer-supported collaborative design and applied it to teaching in virtual design studios. CSCD environments offer great potential for schools of architecture to obtain benefits of bringing together students from different perspectives or to expose students to design problems outside the immediate context of their university. In order to realise these benefits, however, we need to conceive of studio teaching in a different manner to that current held. Instead of focusing on the action of design teaching, such as Schön's reflection-in-action, we need to extend the teaching model to include the deliberation identified by Eraut (1994) as a key part of professional development. To do so, we need to include the abstraction and reflection phases of the PBL model set out by Koschmann, et al. (1994), in particular their stages problem re-examination, abstraction and reflection.

A virtual design studio should expose students to the process of design and not focus only on the final and completed results. As such, the studio needs to require collaboration between nodes. This can be done by establishing teams across boundaries or by exchanging intermediate products. The studio brief should be

written to include an examination of communication exchanges, looking at decision-making and design choices. The tools needed to support this will include archiving tools for textual and graphical communication (including time stamped intermediate snapshots). Students can then be taken back through a design sequence and examine decision making, alternate opportunities and the nature of communication during design. This model of teaching will break down the individualistic and product focused approach typical of studio teaching today. By emphasising collaboration and communication, a VDS will fundamentally change design teaching for the better.



## **7 Professional Implementation of Computer-Supported Collaborative Design**

"On a construction site for a new resort in some remote part of China, to resolve a problem, she boots up her laptop and opens a videophone window to speak via wireless linkage to her structural consultant in Los Angeles. They share concurrent, real-time, interactive access to the CAD three-dimensional model of the project, and they refer to it as they speak. (The model resides on a server at her home office in Hong Kong). After some discussion, she decides to bring the client into the conference; he happens to be in a hotel room in Tokyo, as the others can see from the additional video window that now opens. The problem that concerns them is one of site access – a landslide has unexpectedly created difficulties in locating a bridge – so she instructs an interface agent to find some relevant satellite images so that the conferees can assess the extent of the damage and consider new locations. As they speak, the agent searches the network and soon reports back with what is needed. A course of action agreed upon, the architect sketches the solution on the spot and speaks to an assistant in Hong Kong to give instructions on working out the details. The assistant modifies the definitive geometric model of the project, and a few days later electronically transmits change orders to the contractor's head office in Seoul." (Mitchell, 1995b, p. 59)

This description of an architect using the Internet to accomplish her work is beguilingly simple. With the rapid development of supporting technologies this has quickly gone from wishful thinking to feasible. That is can be done at all is not only a matter of technology, though. A number of changes have occurred in professional practice which have enabled it to happen.

The prospect of virtual offices and digital collaborations are seducing many and spawning considerable output describing the mechanics and experiences of collaborative design. Uses include setting up homepages for clients to facilitate communication between client and project teams, communicating between construction site office and design office, sharing financial data regarding projects with clients or staff as necessary, bringing together staff in branch offices working on a project and creating a virtual practice from a collection of independent practitioners. Many of these have been described elsewhere (e.g. Section 3.5; Kvan, 1996). Indeed, multimedia tools for interaction are presented as the panacea for our frustrations with prior experiences in the difficulties of integrating computers into design work — what works graphically must be suitable for design applications.

This increasing interest in technology in practice arises from a number of factors. Coyne, et al. (1996) identify three reasons that practices change and adopt technology. In the first, rational decision making causes the firms to consider technology as just another variable in practice which is adopted when it can be rationally justified. The second is technological determinism which perceives

technology as the prime cause, above social or work factors, to change. The third is the praxis model in which technology is regarded as a tool to carry out specific work, with the emphasis being on the human work context, not the technology. In this last model, the methods of work affect and are affected by the technology. This last is the model which is adopted here in this analysis too as it is supported by the project focus which has been identified as the basis of architectural success (Coxe, 1989). The praxis model also allows for a plurality of approaches which includes not using computer tools when appropriate (Coyne, et al., 1996, p. 522).

Architectural practice is increasingly becoming a knowledge business, that is, a business whose value is derived from the expertise and knowledge of the members of the practice. No longer is the practitioner reliant on local presence to obtain a commission. Some practices have become truly global, able to deliver their services in locations wherever they have an architectural value. For others to compete in the same arena they must become adept at delivering their expertise wherever it is needed. These practices have entered into a professional world where their knowledge is of higher value than their presence or their particular skills.

Not all practices are knowledge practices. Using the Superpositioning model of architectural practice described by Coxe, et al. (1987), it is the "Idea" practices which have engaged in selling their knowledge and, increasingly, the "Service" practices which are now competing on this level. These practices are increasingly called upon to deliver their particular knowledge throughout the world, using



whatever communication technologies are available to effect such delivery. Other practices (the "Delivery" practices in the Superpositioning model) will remain forever local, but even they will find it competitive to communicate with their consultants using communication technologies more extensively than they do now. Thus, architects are having to acquire a new skill in communication and computer technologies offer such opportunities. Given the different focus of these three practice types, the technology which can be used to support their work will itself be different.

## **7.1 Learning from the Use of CAD in Practice**

From the perspective of those involved in the design and creation of software for computer-aided design in architecture, the impact of computers in practice has been very disappointing. Our research and experimentation always points to a better future than we see realised. It is frustrating to see the majority of practices using the tools simply as an automation of manual methods. As noted, however, the frustration arises not because the software does not contain the best interface nor tools needed. Instead, the problems can be traced more often to the implementation strategies and philosophies of practice rather than technical problems. For example, Lewis, Shea & Kvan (1990) noted "The relative clarity of individual's roles and (implementation) program purpose both matter significantly. The better each are, the better the implementation." Similarly, Kalisperis & Groninger (1994) noted a clear correlation between practices

satisfied with their CADD systems and their philosophy of practice. Using a modified version of a classification of practices as described in Coxe, et al. (1987), Kalisperis & Groninger found that practices satisfied with AutoCAD were Pragmatic practices while practices classifying themselves as Design/Theory practices were more satisfied with other types of CADD system. This is not because AutoCAD is not a good system or lacks features offered by the other systems, but more that the assumptions made during design of the software about ways of working favour particular kinds of practices.

In Asia, we find a stark picture of a singular approach to the use of computers. Let me describe in some detail the situation which pertains in Hong Kong and contrast it with that found in the United States of America by Kalisperis & Groninger (1994). There is no reason to believe that these patterns do not hold for the rest of Asia although no data have been collected to support this contention. In many aspects of architectural practice, Hong Kong is typical of practice around Asia. What is interesting in this picture is the homogeneity revealed, almost a herd mentality in professional strategies, and its contrast to the USA where more diversity and flexibility is exhibited.

In the spring of 1995, a survey was conducted of all practices listed in the Hong Kong Institute of Architects register (Kvan, 1995). 122 survey forms were distributed, 51 valid returns were received, giving us a 42% response rate. Our survey was designed to identify patterns of use for software in a variety of applications. One respondent noted that it would be better for the profession if all

architects used the same software. While we disagree with the sentiment, it is interesting the degree to which this situation already pertains in Hong Kong. For example, 46% of the respondents use MS Word for word-processing and 34% use WordPerfect — that is 80% covered by just two very compatible systems. Similarly, 46% use the Excel spreadsheet and 22% Lotus, again a highly homogenous situation. The status with CAD systems is even more consistent — 90% use AutoCAD (only 4 practices reported using Intergraph and one used Minicad). AutoCAD also dominates the market for 3-D modelling systems and rendering systems. By comparison, 43% of the practices in the US use AutoCAD.

What was less assuring was the extent to which practices are not using computers to obtain benefits in management activities. There are few accounting systems reported to be in use. 52% of practices reported no accounting system in use, with the most common system being Excel spreadsheets (8%) or bespoke software (8%). Similarly, practices do not appear to use software for managing project progress — 88% of respondents do not use software for manpower resource planning and 66% do not use systems for project scheduling. The numbers are very similar to those found in Australia. Olley (1992) found that, in 1990, 47% of Australian practices were using accounting packages and 28% of the practices used project management software. The lack of systems in these three areas suggests a more casual attitude to firm management than observed in practice in the US or Europe. This is even more surprising given that 98% of practices in Hong Kong use computers and that most practices in Hong Kong are management



conscious to the exclusion of design. Clearly, the singular focus is on producing drawings rather than in managing and developing the firm. This manifests itself in a lack of training offered. 34% of the firms have the policy to hire in expertise when it is needed. 55% try to train themselves and only 11% rely on external training. Training has been found to be an influential contributor to the success of computer implementation (Lewis, et al., 1990).

The emphasis on producing work is reinforced by replies to our section asking practices the extent to which they used computers in each of the six contract phases of a project. 86% noted using systems in the inception phase, 88% in feasibility studies, 96% in schematics, 98% in project design, 96% in construction documents and 96% in construction management. This use is not light, either; 70% of the practices identified heavy use (over 55% of their effort) of computers in project design and construction documentation phases and 54% noted heavy use in construction management. This intensive use of systems appears to be supported in the manner in which workstations are located within offices. 57% of practices stated they placed computers on the desks of those who need them, not in central computer areas.

What we see in this survey is a picture of very 'Pragmatic' practices dividing up the work at hand, choosing to tackle the projects with teams of specialists (project managers, designers, technicians), following a team structure modelled on Taylorist principles of work segmentation. Our survey found that 60% of practices classified themselves as pragmatic practices focusing on getting the work done,

26% provided design distinction and 7% handled more complex work requiring client interaction. This is significantly different than in the US, where only 34.5% classified themselves as Pragmatic, 13.8% as Design and 51.7% as Other (called Delivery, Idea and Service practices respectively in Coxe's Superpositioning model (Coxe, et al., 1987). The Pragmatic practices typically organise themselves into departments based upon task and train specialists to carry out these tasks. These differences in practice philosophies manifest themselves in differences in computer implementation.

### **7.1.1 Lessons Learned**

From the statistics presented in this section, we see CAD rapidly establishing a dominant attitude to computing. This has lead to a segregation of computer usage into 'computer-suitable' tasks and other tasks, (Franklin, 1993) with computers being applied to the tasks on a one-to-one basis (Coyne, et al., 1996, p. 525). This supports the attitude that computers should automate manual tasks and also should mimic those tasks. This attitude to computer usage is widely held and not conducive to improvements in practice nor to obtaining the potential second level benefits of computers (Lewis, et al., 1990; Hammer, 1990; Kiesler & Sproull, 1992; Coyne, et al., 1996; Flemming, et al., 1997).

This segregation in to computing and non-computing is not beneficial for practices nor to the practice architecture. There is an immediate detrimental result — it leads to a degree of deskilling and the creation of CAD operators (Coyne, et al., 1996, p. 531). When asked in the Hong Kong survey how computer use could

be improved, practices noted a variety of ideas, but one message comes forth most clearly — there is a real need for those who use CAD systems to really understand what they were being asked to produce, namely architecture.

This is very consistent with findings elsewhere. All around the world, the pattern has typically been that CAD system are brought in to a firm for use by CAD operators. Over time, practices realise that the quality of the information coming out is constrained by the understanding of those putting it in. Thus, the best way to improve CAD output, both in terms of quality and quantity, has been to ensure that users understand the particular needs of architecture. For many practices, this has meant getting rid of "operators" and letting professionally trained architects use the systems directly without naming them CAD operators exclusively (this point is clearly brought out in Lewis, et al., 1990). Whatever the strategy, the users of systems do have to understand both architecture and CAD systems as well as an office's particular needs. The success of computer implementation in professional practice is less dependent upon the software and hardware features provided than by the compatibility of the software to the strategies of practice pursued by the professionals applying the software (Kalisperis & Groninger, 1994) and the managerial strategies followed in the implementation (Lewis, et al., 1990). What then do these lessons mean for our investigations of computer-supported collaborative design?

Comparing the findings reported in Kalisperis & Groninger (1994) and those reported above, we see a difference in the way computers are applied in practice.



In Asia we find more 'operators' employed to use the systems, perhaps because the shortage of trained professionals places a premium on their work which requires a significant number of para-professionals to support the effort. In the United States, it is now uncommon, especially in Idea and Service firms (Coxe, et al., 1987) to be using the systems. Since these are the two types of firms most likely to be collaborating with Asian practices on projects in a distal context, For collaborative work between different cultures, this poses a significant problem, since the ways in which work is carried out in two collaborating teams is substantially different.

Collaborative practice is not a new idea; it would be wrong to imply that collaborative design does not exist outside CSCD environments. Much of the work in Asia today is in the form of joint ventures which bring together practices from many parts of the world, collaborating with whatever means they can to complete the projects. More indirect collaboration, time-phased with manual exchange of drawings, allows different philosophies of practice to succeed together without exposing the teams to the differences in approaches. Thus, different professional approaches can coexist and support the same goals without clashing. With synchronous collaboration, however, these differences can be profoundly disruptive. Successful collaboration must find its way around these differences and provide means to accommodate them.

To enhance the opportunities for computer-mediated collaborative exchanges, therefore, we will need more than simply multimedia workstations with digital cameras on top. Where the introduction of CAD systems exposed the difficulties

of communication and the division of work within offices, computer-mediated collaborative design will expose the participants to the peculiarities of their collaborators and the importance of communication skills.

The greatest problem encountered so far has not been technological — those problems have been niggling issues which certainly have prevented the potential from being realised but have not fundamentally undermined the notion of collaborative design. The real problems have been encountered in establishing a level of trust and acceptance between the participants, a trust which is fundamentally important to shared design effort. These issues of intersubjectivity have been discussed by Vaitkus (1991) and in Section 2.3. As many practices are aware, there are many problems in teaming consultants in a traditional project setting. In computer-supported collaboration, these problems cannot be avoided and need to be addressed.

Another distraction is the issue of video connections. This issue has been addressed extensively in the earlier chapters. We should remember that seeing the hand that traces the line is not as important as seeing the potential for change in the line. Thus, video-based exchanges such as the Xerox PARC's Media Space (Harrison & Minneman, 1990) demand substantial bandwidth with little added value derived (Easterbrook, et al., 1993). As Easterbrook, et al. note, it is the effectiveness of the communication which matters, not the technology. The two are not inseparable. The richness of design comes from the unexpected opportunities seen in the documentation of the design, a process akin to the

"Joycean communication, leaping to allusions, returning to earlier forms and worrying over details" mentioned in Cheng, et al. (1994). This is the kind of interaction which occurs not only in face to face crits or a design charette but, as research into creativity suggests, in our interaction with sketches and drawings as well (Goldschmidt, 1991; Arnheim, 1996). This tells us that practices should train staff not only to use computers but also to communicate and collaborate. Without inventing a new training method, it seems that the training offered for partnering will suffice.

It is important to consider ways in which such computers can improve the design process, not simply replace (with such process as knowledge systems) or replicate it (as with automated design tools). From our experiences, we see that a virtual studio can be a more exciting place than even face-to-face meetings. Mimicking manual methods and encoding these conventions into systems has not served us well with CAD systems. As noted by Cheng, et al. (1994) "we should explore the rich potential which might come from computer-mediated design processes... collaborative design leads to interesting results often because of fortuitous misunderstandings... Should not the development of computer-mediated design places encourage such ineffable communication".

The tools, data, training and team organisation which make a difference are examined in the following sections.



## **7.2 Establishing CSCD in practice**

If we regard electronic group work to be a social phenomenon (Finholt & Sproull, 1990) and CSCD as a social process (Mitchell, 1995a) as understood in Section 2.5.1, then we see that a key issue in implementing collaborative systems in practice will not be the technology but the nature of the collaboration. Computers are not deterministic and can lead to a variety of modes of work (Eason & Olphert, 1996). In as far as CSCD tools require users to change their means of communication (Kurland & Barber, 1996), the key to successful use of these tools is to establish new modes of working and new means of communicating, not to try to force the systems into our existing modes.

Underlying the use of CSCD is collaboration. If we are to change our modes of work, we must consider these from the perspective and demands of collaboration. If this is the case, then we can use the six facets of successful collaboration in work settings identified by Mattessich & Monsey, 1992 (1992) as discussed in Section 2.3 above to consider the implementation of CSCD in practice.

### **7.2.1 Environment**

Environment is the term the authors use to describe the geographic and social locations of the collaboration. This has to be extended to cover the concepts of distal collaboration by including the multiple environments of the team's component nodes. As noted earlier, this spreads the responsibility for managing the collaborative environment to multiple people.

The environment must be flexible. As we have established above, design collaboration is a loose coupled activity. This implies that the elements of the collaborative process must be flexibly related and that the environment in which it is carried out is accepting of the participants and their differences. Computing tools used to support collaborative design also fit within a larger context of computing tools within each practice in the collaborative team.

Computer-supported collaborative design encompasses a wide variety of tasks. The context of professional practice is somewhat different from that of teaching in that the range of activities is far greater, with many of them occurring on different projects concurrently. Thus an architect may find themselves preparing sketch concepts for a proposal meeting with one client while reviewing working drawings on another and negotiating the design of an air-conditioning system with a consultant within the same day.

The multitude of tasks is supported by a variety of tools. As Flemming, et al. (1997) have pointed out, the D in CAD can mean drawing, drafting or design. Drawing encompasses any program that allows users to leave traces on the screen, such a paint program. Drafting implies a more structured construction of the drawing and therefore requires a larger set of more complex tools to create the drawing. Design implies support in decision making, something that commercially available systems today do not offer. Some drafting systems have extensions to them which make drafting more efficient, but do not cross the line into design because the systems cannot handle constraints, monitor work and give feedback,

etc. An architect can use all of the variety of tools described by this one letter and more, including tools to handle design, management and communication. These tools will deal with text, graphical and numerical data.

Experience with CAD has illustrated the importance of considering this larger context. Some clients require practices to purchase and use particular CAD systems on their projects. For example, the several government departments in Hong Kong require architects to use AutoCAD while other branches require Intergraph. Observation of practices which have been required to use two systems concurrently show that there are problems which arise directly from this situation. The practice, the staff and projects suffer as training is duplicated to accommodate the multiple systems. Staff members are not easily moved from one project to another as their skills are not transferable. The practice and the projects then suffer. The same can happen in a distal collaborative project if particular systems are demanded of participants, violating the principle of inclusiveness and flexibility in Section 4.3. If this is violated, the project stresses will increase and the possibility of project success is decreased.

The environment must be appropriately defined and focused. Architectural success is obtained at the project level. A successful firm is project focused (Coxe, 1989; Cuff, 1989; Shibley, 1989). From this we can conclude that success for a CSCD experience can most likely be built at the project level, not a firm-wide level. As the factors below are considered, they should be implemented at the project level.



### 7.2.2 Membership

As Harré (1993) reminds us, a collaborative team has to be assembled and created. Participants have to gain a meaning in their roles through their participation. Participation starts with defining a membership — who is a part of the team and who is not. Since team members are remote from one another, membership needs to be clearly defined and communicated. While collocated members can observe someone walking into a meeting and can deduce the membership status of the person from actions, distal collaborative environments make such observation and deduction more difficult. Anonymity is more easily assumed and can, as Vaitkus (1991) notes, be very disruptive.

Partnering tell us that an effective project group must have the appropriate members, known as the stakeholders (Larson, 1997). Each member in the group has to have a role (O'Doherty, 1976). The stakeholders need a voice (Allbriton & Smith, 1996). The purpose of defining membership is to allow all participants to understand the nature of the project, their contributions and their voice.

As noted earlier, Shea & Guzzo (1987) have identified three items which determine the success of group effectiveness: task interdependence (how closely group members work together), outcome interdependence (whether, and how, group performance is rewarded), and potency (members' belief that the group can be effective). In establishing a project team, the leader must ensure that these three issues are addressed. Successful use of computer-mediated collaboration will require higher task interdependence than face-to-face since the tools impose a

burden on communication, the motivation will therefore need to be higher. Similarly, a collective belief in high potency will result in a more successful team; establishing that potency at the beginning will be a team leader's task. Membership helps to build and define that potency.

The roles within the collaborative team must be differentiated and leadership is essential (O'Doherty, 1976, p. 30). Sonnenwald has reminded us about the contribution that particular roles make to the success of a collaboration. In her research she identified thirteen roles as present in an interorganisational collaboration, of which five were essential:

- a *sponsor* to secure acceptance and funding for the project
- an *interorganisational star* to lead interactions with others in the larger organisational units and beyond to external organisations
- *intraorganisational stars* to transmit and filter information about goals, subgoals etc.
- *intergroup stars* to represent groups in design and task discussions
- *intragroup stars* to facilitate interactions within groups (Sonnenwald, 1996, pp. 289-291)

These roles ensure that the participants in the collaboration are adequately represented. In addition to these five roles, we should add a sixth, the process facilitator. The importance of the facilitator has been noted as important in all collaborations (Mattessich & Monsey, 1992), not only where the technology or processes are complex and user could benefit from guidance (Shelden, et al., 1995).

The members of the group will define part of the social context within which the project is executed. An important component of this context, as Latour (1987)

helps us identify, is the network of knowledge for the project. For the project to be successful the network must be sufficiently extensive and inclusive to hold the knowledge necessary to complete the work. The knowledge needed is not only that which is related to design and construction. The knowledge must include knowledge about the tools being used and the processes employed as well as the technical skills of designing and building. Specifically, in a CSCD setting, team members must know, or know how to find, among the members of the team information related to the selection and operation of computer tools and how to find information to improve teamwork.

### **7.2.3 Process and structure**

There are two aspects of process and structure which are pertinent to this discussion. One is the process and structure of the team, the other the process and structure of the project.

As noted in the section above on membership, the team must have the appropriate roles defined in order to define a proper process. Most important role noted is that of an overall facilitator (Mattessich & Monsey, 1992; Sonnenwald, 1996). When technology is introduced to the communication and collaboration process, the role becomes more important (Shelden, et al., 1995). Sonnenwald has identified that facilitators are needed also to effect communication within and among the groups of a collaborative team.



The process of the project must also work to build the "team-like sensibility" (Cuff, 1989, p. 84) which is essential for success. To do this, the team responsibilities must be defined to include the fiduciary responsibility to others within the group (Vaitkus, 1991). This includes understanding the spectrum of "social offerings" (Vaitkus, 1991, p. 166) available for us to use as we fulfil our fiduciary obligations, the gestures of attentiveness to others within the group such as responding to initiatives of others. Text communication can be terse and can cause miscommunication which, without the opportunities for immediate feedback available in collocation, might cause extended problems (Easterbrook, 1996). The gestures to which Vaitkus refers can include turn taking, attentiveness, responsiveness and respect. Training may be needed for participants to develop skills appropriate to the tools and environment of the collaboration.

Additionally, we need to consider the potential life of the project. If the project is expected to be drawn out, as many architectural projects are, the facilitator will need to consider the mechanisms of removal and acceptance of members as they leave and new ones arrive in order to maintain the team-like sensibility and fiduciary responsibilities.

As the work in partnering has shown, team effectiveness can be increased by attention to the processes engaged in a project. In particular, partnering has demonstrated the importance of engaging the members in a process of team building. Larson (1997) has noted that project success can be correlated with building team effectiveness through team building sessions, conflict identification,

problem solving process established before project starts and arriving at agreed objectives and responsibilities to develop a joint project charter. This process is most effective when external consultants used to facilitate the relationships between key participants (Larson, 1997; Mattessich & Monsey, 1992) since these external facilitators can remove themselves from allegiance to any particular member of the team.

While no-one has yet developed and tested methods for partnering in a distal configuration, the online team can use the techniques to help the project be defined. If the team members cannot come together for a partnering session before the project starts, an external consultant can be used to facilitate a partnering session online using GPSS or CMC tools. These environments would allow the team to address the issues which Larson identifies as key to project success.

In addition to the processes of the team, we should consider the structure of the practice. Although Coxe (Coxe, 1989) has reminded us that a project focus serves to support architectural excellence, projects do exist within the context of a practice. Thus the practice structure has to be considered.

As tools become seamless, the structure we have traditionally imposed on the practice changes. It has already been reported that some practices have physically reconfigured their practices to accommodate the use of CAD, allowing project teams to work together more effectively than when seated in rows of drafting desks (Day, 1993). Other practices have removed particular roles as they

assimilate computers, typically roles such as typists or draftsman in which the major part of the work is transcription of information from one media to another (Coyne, Sudweeks & Haynes, 1996). New roles will appear — many practices now have web masters and web page designers.

With the introduction of CAD, architects have seen the act of drawing change from the laying of lines on paper to the organisation of data in a database (Coyne, et al., 1996, p. 528). This perspective brings with it new opportunities (Coyne, et al., 1996, pp. 526-527). Some practices have realised that the change goes well beyond this and recognise that architecture can be considered process not of aligning bricks or configuring space but can be reformulated as the manipulation of data, some of which is expressed in physical form, other in organisational form or functional characteristics of a building. Their work has then moved from design of buildings to design of data, be it data to be translated into physical form (for example, a building), data management (for example, facility management) or web data. One practice which has made such a bridging and now operates in all three realms of data is Eastlake in Chicago (<[www.eastlk.com](http://www.eastlk.com)>). As such changes to the purpose of the practice come about, it is inevitable that the structure of the practice changes too.

As the practices become virtual, we will find the layers of management built up in a location-based practice falling away. The hierarchy expressed in a number of titles, such as junior architect, project architect, project manager, principal,



partner, will change of its own accord. In their place will be structures more suited to the temporal nature of the collaborations.

Finally, we need to consider the structure of the project processes themselves. As identified in Chapter 3, few CSCD projects have yet to explore the potential of computer-supported communication to facilitate better process and structure. The findings summarised in Nunamaker, et al. (1995) indicate that there is tremendous potential for systems which introduce a structure to group decision making meetings. While architectural projects may be sufficiently complex that an overall process cannot be defined and enacted through GPSS, it is possible that GPSS can be beneficially applied at specific points in a project.

#### **7.2.4 Communication**

Communication is central to collaboration. In order for it to be effective there must be a mode of communication. The technologies of communication, textual, oral, visual, and data, have been reviewed in Chapter 4 above. This will not be effective alone, however, as the means and style of communication are also important. Kurland & Barber (1996) have observed that participants in CSCW must adapt their communication arrangements to the new context. Our experimental findings reported in Chapter 5 illustrate the same result, although we found it happening without explicit direction or intent. In practice, however, the risks in terms of cost or legal exposure are such that the team members may need to address issues of communication effectiveness explicitly.

Some practices already address this issue in the process of partnering. As Allbriton & Smith (1996) have noted, partnering training should include training in personal style awareness as they find this a useful tool for elucidating mechanisms for success in communication. Personal style awareness training takes the perspective that if you do not know how to interpret the communications from others, you may misinterpret the content.

Personal style awareness is a poorly defined area with primarily empirical research. There are a variety of tools for such training; one which is commonly used is the Myers Briggs Type Indicator (MBI) (Myers, 1993). MBI identifies four dimensions to a personality type and the various permutations of these four dimensions will be manifested in a variety of behaviours. Once team members understand the permutations, they are able to adjust their own behaviours in response to another's exhibited behaviour. Tools such as these provide team members with better understanding about how others behave, particularly in the communication context of the project.

### **7.2.5 Purpose**

The purpose of the collaboration must be made clear as must the purpose of the project. Part of establishing the purpose needs to be build a shared understanding of the potency of the team (Shea & Guzzo, 1987). Additionally, in a CSCD environment we must address the purpose of the collaborative tools so that team members understand role of the tools.

In partnering, part of establishing the purpose of a project is identifying the expectations and goals of the team members, the "stakeholders" (Allbriton & Smith, 1996; Larson, 1997). The process of identifying and resolving any conflicting expectations and goals becomes more difficult when the team is distributed over several locations and time zone.

Common purpose needed for a group to hold together (O'Doherty, 1976, p. 30). The purpose must include collaboration; according to Shea & Guzzo (1987), the success of a group depends upon their outcome interdependence. If the group outcome does not depend upon collaboration, the group will tend not to work together and degenerate instead to lower levels of joint work such as coordination, co-operation (Mattessich & Monsey, 1992) or simply parallel work.

### **7.2.6 Resources**

Mattessich & Monsey (1992) have noted that the most important resources in the collaborative studies surveyed were a strong financial base and a skilled convenor or facilitator. For architectural practice, this means that the costs of collaboration must be considered when negotiating the project fees. The project team must also consist of a facilitator, as well as the roles outlined in Section 7.2.2. In addition, there are three resources which Mattessich & Monsey do not address which are particular to CSCD and architectural practice: the tools of communication, the data generated and training. Each of these is addressed below.



### 7.2.6.1 Tools

According to Schmidt & Rodden (1996), a CSCW environment must be made up of a variety of tools in order to support the diversity of tasks which must be accomplished. It is likely that a CSCD environment will also need to permit the use of a variety of tools to address the range of architectural activities undertaken.

Fitzpatrick, et al., 1996 observes workers in a virtual team which is also collocated and finds they have strategies for working in the virtual. Because each worker cannot see the whole task, they create online representations of outstanding tasks in their part so everyone can see the status. They use multiple modes of communication, not only e-mail or posting lists. These are supplemented in various forms by telephone, and, because they are collocated, they can visit each other. These tools allow them to take part in a multitude of different and overlapping social worlds in order to get their work done.

As demonstrated by the numerous reports of practices already engaged in different aspects of CSCD (see Chapter 3), the technology to get started already exists. The initial applications range from simple exchange of data files (Ross, 1997) through to web-based drawing access (Phair & Angelo, 1997) and video surveillance of site progress ("ZGFNet", 1997). As experience increases and as commercial vendors recognise the market potential, we will begin to see a selection of tools for architectural collaboration and probably market dominance by particular systems. It is unlikely, however, that there will ever be a single tool which allows all the forms of operation and communication needed. When starting a project, the

team must identify the range of tools which maybe used and test the transfer of data between them.

Project management is an essential activity of a project which must be supported in a CSCD environment. Managers need to have necessary tools to monitor the progress of projects. As practices become less connected to place, the traditional means of management change too. Supervision is more difficult when all the data are locked in a black box. Many architects spend their day out of the office and come to know the status of projects by walking around the office observing the drawings on the drafting desks. When all the data are saved on a server, we need new tools to see what has been done. This does not only mean the project scheduling systems often found in architect's offices to monitor time, resources and budgets (accounting systems such as Harper and Schuman or project scheduling systems such as Primavera). Document managers can be used, for example, to bring up all drawings worked on in a day, so the principal can see what has changed. Comparisons can be run between documents to highlight differences.

#### **7.2.6.2 Data organisation**

The importance of data in a CSCD project is obvious. The issues have been discussed in Section 4.4. Within the context of a project, however, there are a few aspects worth rehearsing.

The tracking of data in a computer system is a complex and burdensome process yet critical to effective use of the technology (Sanders, 1996), but probably no more burdensome than doing it manually. Demands for data management in all practices has increased as the regulatory and litigious environments of practice become more demanding. A large number of documents are produced in the course of a project. These documents must be stored so that they are retrievable.

In collaborative projects, we have to ensure that team members are working in a co-ordinated manner on the same version of the design. The management of CAD drawings, for example, has been the subject of much debate and various standardised methods of organising CADD data have been promulgated, for example the American Institutes of Architect's guidelines (*CADD Layer Guidelines*, 1990).

Within collaborative projects online the issue becomes even more important as files are shared directly by all participants (Wojtowicz, et al., 1993). Strict adherence to file naming, file organisation and tracking methods must be used. Software systems exist to assist in such tasks and are known as document or drawing management systems (e.g. AutoManager). These systems track file names and locations along with access information (who edited the file last and, if it is open, who is using it). Audit trails can be traced to determine the history of access and changes. These systems as yet do not address the issues of tracing intent raised by Saad & Maher (1996). Integrated data models will be developed



(Fruchter, et al., 1996; Kalay, 1997; Goode & Scarponcini, 1997) to facilitate CSCD.

### **7.2.6.3 Training**

The degree to which staff are properly trained has a great effect on the success of computer implementation in practice (Lewis, et al., 1990). If staff are to engage in collaborative design using computers, it is essential that they become more conversant with the technologies of drawing to a level of virtuosity so that the tools do not disrupt the conversations of collaboration. Training is therefore central to the success in implementing computer-mediated collaborative design. To be effective, however, we need to reconsider what is commonly passed off as training in the corporate world.

Our experiences with CAD training provide a good example. Most architects coming into practices in the 1980s received CAD training since the majority of the workforce at that time had not been trained during their professional degree courses. This training typically focused on command level interaction with the systems — the location of commands on menus and their particular associated action. Most exercises were carried out on graphic images which had little to do with the professional work of the office they were joining (a favourite training drawing was the Space Shuttle since this came bundled with the training material provided to authorised CAD trainers).

This kind of training has been demonstrated to be inadequate. Bhavnani & John (1997), for example, examined the use of CAD systems in practice (at the U. S. Army Corps of Engineers in the United States) and found that users acquired a very small range of knowledge about the system and then persisted in using the system within this range, even if it was inefficient. Neither CAD system design nor the length of experience of the user could ensure that efficient ways of using the systems developed.

Bhavnani & John show that the key factor to efficient use of CAD and other tools is the concept of *aggregation*. Aggregation is the ability to group disjoint elements in various ways and to manipulate these groups with powerful operators. That is, it is the ability to decompose and recompose the task at hand into means of acting which may at first not appear obvious. They extend this concept of aggregation to state that training for efficient use of CAD must not focus just on commands and command strings but has to encompass training in the strategies of aggregation.

We can assume that this approach to training will benefit user of tools in CSCD. Since CSCD environments are likely to be compilations of a variety of tools (Schmidt & Rodden, 1996), the environment will be complex. The effectiveness of collaboration will be affected by a users the fluency of the tools, making training very important. Conversations interrupted by clumsy articulation of spoken language or drawn language (to use Schön's term) will be less fluent and less communicative than those supported by who are fluent in the medium.

A profession can be regarded as a process of lifelong learning. Professional associations recognise this now with the requirements for continuing professional development (CPD), including continuing professional education (CPE), in order to maintain licenses to practice (Eraut, 1994, pp. 10-11). There is tremendous potential for CSCD technology to be used in continuing professional development, combining the applications in Chapter 6 with those in this chapter.

Training will not only have to focus on the mechanics of system use or specifics of project process. As users become more conversant with the technology, they will change the ways they use it to fit their goals (Sherry & Myers, 1998, p. 136) and change the way they work to adopt the technology (Kurland & Barber, 1996). While we can allow this to happen in an unstructured manner, with each participant exploring and discovering their own methods, it is probably better to guide this change. We must train staff to consider these changes and establish mechanisms to manage the change. Change in professional settings is itself often perceived as problematic or with fear when it can be seen as an opportunity (Wright, 1997). The alternatives are even worse: allowing it to happen unmonitored or preventing it from happening. Thus the training required to accommodate CSCD will be at three levels: technology, project process and change management.



### 7.3 Discussion

Since we are still in the early stages of experimentation, most of this research in collaborative design exists outside the professional context and describes instead experiences in teaching settings. When tested against professional practice, however, many of the expectations of computer-mediated collaborative design appear to be excessive. Some fundamental capabilities have not been provided and some aspects need additional investigation for the benefits to be realised.

Nevertheless, basic tools are available to get started. There are already practices which have implemented broad networking applications (Phair & Angelo, 1997; Sanders, 1997; "ZGFNet", 1997) while others have been successful using simpler configurations (Ross, 1997). Other practices have used the technology to transfer expertise from one project to another (Day, 1993). Some have applied it to sharing data between participants and projects (Phair, 1996; Savage, 1996). Several practices have applied the technology to address particular client needs which a single firm could not meet, with small teams serving substantial projects by teaming and overcoming distance ("Virtual A/E firm", 1994; Novitski, 1996; Laiserin, 1996). Most interestingly, none indicate the use of video technology has been essential to their success. This supports the postulation in this thesis that successful collaboration, at least in the professional context, can be achieved without the video-supported communication assumed by the situated model of design.

There is indeed much that the technology does not handle well at the moment and for which practices will either need to establish procedural mechanisms to accomplish the ends or, if possible, ignore the issue by working around it (something practices are typically successful at). Data co-ordination is a significant technical problem. The dimensions of the problem were described in Chapter 4. Exchanging data is a straightforward proposition now but implementing a co-ordinated database across boundaries of practices, space and time is not. Some commercial vendors are well advanced in providing solutions but their solutions tend to be proprietary, not inclusive as needed by CSCD. Whatever the tools used, every practice will have to work toward making the tools fit seamlessly into their project setting.

In addition to technological issues, there are many other issues to address. The real challenge is not technological but procedural. Experience with CAD systems suggest that this will probably be more difficult than devising appropriate tools. From that experience we see that greatest benefits are realised when the work is restructured, even to the extent of reconfiguring the physical layout of the office to take advantage of new work processes (Day, 1993). Many practices still have fundamental problems in project execution. Some have sought technological solutions to these problems, for example by introducing CAD systems to improve the production of contract documents. Most have found that these technological solutions do not work, they merely exacerbate the problem.

Training is essential, and not just training in the functionality of the software. Process change has to occur and it is this change which the training has to support. As Dave (1995) notes, users have to learn the capabilities of the systems available and adapt their activities to these media. This is nothing new — we have to do that with manual methods too. Architects choose carefully the media they use to convey particular ideas (see for example Renzo Piano's discussion about drawing and model making in Robbins 1994, pp. 126-149). Training can also help in CSCD by addressing questions of intersubjectivity and project process — how teams work together in all settings. Much of the training offered in support of project partnering will directly assist CSCD. We do not have the depth of experience yet to tell us how to use the new technology to best effect in practice. This is an area of research which deserves substantial attention.

When using computers to assist in collaborative design, the urgency of changing the way work is carried out is even more pressing. Computer-supported collaborative design changes the practice of architecture and, as noted by Weld Coxe, “The practice of architecture is really one completely interwoven activity, and this is a key to excellence” (Coxe, 1989, p. 98). We can have no success if we do not consider the whole.

## 7.4 Conclusion

There are substantial possibilities for practice to benefit from computer-supported collaborative design. Since the technological requirements for obtaining the



benefits are low, with effective collaboration being achieved using low bandwidth and simple modes of communication, it is within the reach of most practices. Any practice which wishes to employ CSCD will need to pay close attention to the processes in which they apply it. In particular, the practices will need to make the effort to identify the environment, membership, process, communication, purpose and resources of the collaboration. The major challenge in applying CSCD in practice is not in the technology, but the manner of application.

## 8 Conclusion

The proposition of this thesis is that successful computer-supported collaborative design is an expert activity that can adapt to a variety of modes of communication. As such, it does not rely on tools which seek to replicate face-to-face design contexts. As outlined in the introduction, this proposition rests upon two related understandings — that design is not a situated activity and that designers, as experts, will successfully accomplish their work in a wide range of environments, adapting themselves and their communication to the context in which they find themselves. It was postulated that the success of collaborative design is largely the consequence of the knowledge and experience of each collaborator — their expertise — not the consequence of the situation in which they design. Computer tools to support distal collaboration should therefore not seek to simulate the

situations of face-to-face collaboration but look to obtain greater benefits of the process.

This proposition has been demonstrated to be true. The thesis has established that collaboration is central to architectural design. In order to arrive at a successful collaborative design outcome, we need to ensure that both design and collaboration are successful. To this end, we have identified the characteristics of the design process which support design excellence and the aspects of the collaborative process which support successful collaboration.

If collaborative design is to be supported by computer tools, we need to understand the process of collaboration. This thesis has examined collaborative design and identified that it is a loose coupled process which can therefore be supported by a variety of tools to support the loosely coupled components rather than demanding a monolithic or integrated design support tool. This concurs with the findings in CSCW research which finds that CSCW must be supported by a collection of tools to fit individual tasks, not integrated systems specifically for CSCW.

In order to support design, we have reviewed design methods models and identify that design can be seen in two ways: a systems approach in which design tools can take over aspects of designing or a process approach for which the tools needed will be non-intrusive support but not tools to take over design actions. We conclude that design can be understood in both models and that both types of tools



are needed, depending on the nature of the design process being supported within the loose coupled model.

To understand collaborative design better, it was reviewed more closely in three aspects: is it social, is it situated and is it cognitive. We conclude that there are social aspects of design which must be supported, that design is not situated and that the cognitive model of collaborative design does not preclude the social aspects identified.

Review and examination of research in CSCW shows that three types of benefits have been identified: process gain, better communication and better results. By reporting and reviewing conference papers in the period 1993-1997, we find that CSCD research has focused on better communication in an unstructured exploration of virtual design studios. Additionally, we find that the assumption in many research projects is that design is situated. From this review, areas have been identified in which further research can be carried out.

The thesis reports an experiment in which it is demonstrated that design collaboration is an expert act in which the expertise of the participants is dominant to the situation of the collaboration. The experimental findings are that the same quality of design can be produced in two modes of communication, one limited and the other broader. We observe that the design collaborators adapted themselves to different modes of communication readily, demonstrating that design is achievable in a variety of communication modes. The experimental

results confirmed the contention that design was an expert act. From this, we conclude that computer tools to support design can be varied, including those with low bandwidth capacity.

These findings are then applied in the context of teaching. From this we identify that virtual design studios can be structured to better effect by using the capability of the technology to maintain traces of the design process. This allows the students to examine and deliberate on the process once it is completed, extending their learning experience from the action of design to the deliberation of design. Thus the technology offers something which is unattainable in a traditional design studio.

Applying the findings to professional practice, we find that the focus must be on the process of implementation. Communication supports the designer's ability to act upon their expertise. The processes which support communication in a professional setting are influential to the outcome of a project. Since users will adapt to the technology, their adaptation must be supported with training, process and project formulation. It is concluded that the primary effort in implementing CSCD in professional practice must be on establishing successful processes to support design.

## 8.1 Future research

This thesis has identified a number of opportunities for future research. These can be classified into two groups: technological and process.

Research into technological aspects of CSCD can be usefully pursued to identify the tools needed to support collaboration in a variety of low band width conditions. Tools currently used in these settings do not leave traces of the collaborative effort, making it difficult to engage in the deliberative processes in teaching, for example, and review the design learning. In collaborative work, the tracking of communication and intent has been identified as important but there are few tools yet with which to do this in a loose coupled environment. This suggests a variety of specific tools to investigate. For example, there are opportunities to extend MOOs into design and design reviews; agents can be developed to help search, track and monitor design co-ordination; web interfaces are needed to track and assist in version management of design. A wide variety of tools are needed within this loose coupled environment.

While there is little research completed in the technological support of collaborative design, there is even less in the area of process support. As has been shown, appropriate processes are essential in supporting successful collaboration. There is considerable opportunity in identifying and developing such supportive processes, both for synchronous and asynchronous collaboration, for teaching and professional practice. For example, we need to understand how to extend partnering methods into virtual collaboration; pedagogical methods need to be



developed to support the deliberative design studio; a greater understanding of negotiation in design is required to understand how the tools can support negotiation. We do not as yet understand the types of tools required to support particular processes.

Whereas the issues outlined above are somewhat general and perhaps longer term in their nature, we can identify some immediate experimental investigations that are needed in order to answer these longer-term questions. Specific experiments that might be undertaken include:

- Novice vs. expert communication in design - do novices need a different set of tools to support communication than experts? It may be postulated that experts work with clearer internal representations of problem solutions while novices need more support in the form of external representations. In design, this would suggest that novices require tools to support these explicit representations while experts are able to produce results of equal or better quality using less articulated representations. In carrying out comparative experiments using novice-novice and expert-expert pairings, are different results to be found?
- One of the implications of the results in Chapter 5 is that peer learning may be more effective over chat line connections rather than video links. This can be explored in a structured manner to see if this is true. Experiments identified in the point above may shed light on the importance of representational methods

for novices and experts that contradict or supplement this view. Depending on these findings, it may be found that chat line better supports peer learning between less experienced (younger) students or is better suited for use by more advanced students. On the other hand, we may find the opposite, that experts come to rely more on external representations through experience while novices remain unconstrained with respect to representational form.

- Effect of time - is communication different in design collaboration that continues over extended periods rather than discrete sessions of one hour as tested here? Do experts handle short time frames better than novices? Is the nature of communication changed when the problem is not time constrained? Experiments in which subjects solve problems with different perceptions of time constraints can be run to observe the effects and the results fed back in to the experiments conducted in Chapter 5.
- In what way is communication in collaboration in a knowledge lean task different to that in a knowledge rich collaboration? Contrast communications in a problem lean task, such as the "twelve balls" problem, with a design task. This is interesting because a great deal of the research done in areas of problem solving and collaboration has been carried out with unnaturally knowledge-lean tasks. The results of these well documented experiments need to be validated in knowledge rich task environments such as design.

The experiments above consider different facets of the role of textual communication in problem solving. In contrast to audio, video and diagrams, it appears that text exhibits particularly beneficial communication characteristics in the context of problem solving. From early results in subsequent research, we observe that text allows deeper and broader exploration of problem spaces. We can hypothesise that this may be due to generative qualities of text in contrast to diagrams and the relative permanence of text in contrast to spoken communication. A central goal of our research is becoming to delineate the specific beneficial characteristics of text in knowledge-rich problem solution.

## 8.2 Summary

The concluding observation of this thesis is that CSCD has great potential in both teaching and practice, but only if it is applied to extend and change the way we teach and work, not if it is used to replicate our current efforts. This thesis has demonstrated the proposition that successful computer-supported collaborative design is an expert activity which can adapt to a variety of modes of communication is true. The implications of the proposition have been tested and explained.



## **Appendix 1: Communication technologies for practices**

This appendix presents a perspective on cost in mid-1998 for various communications technologies which would be used to implement CSCD. A more extended version of this was published as Kvan (1998).

Since 1960s AT&T has been trying to persuade us that videophones are the way to go — grandma just can't live without the grandchildren, and your boss or your client just can't live without seeing your face. Although the early desktop systems never succeeded, room-based systems such as Picturitel have been developed and are now commonly available with large screens and fairly good sound quality. For example, using 1998 prices in the United States, a one hour video-conference call

from the US to Hong Kong (including all room and line charges) is about US\$870. Two problems with these telephone-based video conferencing systems is their transportability and their cost. When you are on site, Picturatel is not an option. If you are planning to use the connections for extensive collaboration, the cost is a major problem.

If you are willing to go down-scale and use a computer-based video system, there are cheaper alternatives. Access to the Internet is now widely available. All you need is a telephone line to your Internet Service Provider (ISP) and you are in business. Establishing an account is not expensive — most ISPs in the US now offer access from around US\$20 per month. The quality of your connection, however, can be much influenced by the way you connect to it, and there are some important technological developments being made at the moment.

Most people can get access using a high-speed (56kbps) modem on a telephone line. Priced at around US\$100, these modems are able to give you access to the Web with reasonable immediacy (although they certainly don't operate at a full 56kbps). It is not unusual to have voice and image disconnected by up to a minute when using these systems over busy networks. Better access can be had over cable modems, ISDN lines or digital subscriber lines (DSL). As the access improves, the cost escalates. Cable modems are typically rented for US\$30 per month (if you have a cable hookup). Cable companies will talk about access speeds of 3 Megabits per second (3 Mbps), but you are likely find it is really around 96kbps when you actually get on.

ISDN takes the cost up higher, lines cost US\$75 to US\$125 per month, ISDN modems cost US\$200 to US\$500 to purchase. Access on these lines is 56kbps to 128kbps, depending on your connection. In some phone company territories, ISDN is very well supported and cheap, others will make it virtually impossible for you to have a connection made to your office.

A new technology may replace ISDN. DSL are being widely tested and have the backing of many technology and Internet companies. DSL modems can be purchased for US\$500 and the monthly line fee then costs you between US\$30 to US\$300, depending on where you live and how many lines you need (businesses will need more than one line). Higher-speed access to networks means more data can be pushed back and forth between users in the same time. This higher transmission is called higher bandwidth.

What these prices show is that high-speed access is possible and increasingly affordable. Will all this access bring you into the world of digital design studios? What we are finding is that functionality of video conferencing has not improved much since the first videophones. Video images are very demanding of bandwidth, consisting as they do of a large amount of data in even a small image. As the video image gets bigger than a postage stamp, the amount of digital data being transmitted escalates dramatically. Audio transmission is a little better, the files being somewhat smaller. Commercial video-conferencing links use two high-bandwidth (128k) ISDN lines just to support the audio and video feeds; computer



connections require extra lines yet. Even then, the video image is grainy and periodically falls out of synchrony with the audio feed.

## **Appendix 2: Examples of protocol coding**

A one minute segment of a protocol is presented here encoded in the two coding methods used — collaborative process and design content. The protocols come from a chat line condition and exhibit the errors of spelling and grammar common in these protocols. The experiments generated over 180 pages of protocols, all of which were encoded using both methods.

Collaborative process

Codes used:

- N negotiating
- E evaluating
- I interface specific
- C clarification

Time	Participant 1	Participant 2
5:33:36	hello, daniel	
5:33:54	give me a message and then we start [C]	
5:34:01		ok
5:36:13	have you finish reading the program [C]	
5:36:19		not yet
5:38:20	I have the following concept: [C]	
5:38:33		ok i have finished reading [C]
5:38:45	the site is very steep, the path should be zig-zag [N]	
5:39:13		yes
5:39:30		i have some question
5:40:01		what is the meaning of '%' on the item max angle [C]
5:41:03	The % is the same to 1:2, 1:3, etc.curvilinear landscape and path can be form to soften the orthogonal grid of the building [C]	



Time	Participant 1	Participant 2
5:41:40		is '%' mean angle degree [C]
5:42:09	yes, $1/2=50\%$ $1/3=33\%$ , etc [C]	
5:42:17		ok i see
5:42:27		ok let's start
5:43:09		should we start from the design of routes [M]
5:43:12	do you agree to put seating area and playground in central part of the site [N]	
5:44:06		ok. But why should it at the central [N]
5:44:34	easily accessible from three streets [N]	
5:45:16		is would also be at the central but near the east [N]
5:45:30	yes	
5:46:21	point no.1,2 is directly related to point no.6. could we use some curve to direct the flow and create sense of arrival [M] [N]	
5:47:06		ok
5:47:09	the playground should be circle [N]	
5:47:23		could be
5:47:41		where should be the car park space [N]
5:48:16	exiting car park is in the middle road [C]	
5:48:46		ok sorry

Time	Participant 1	Participant 2
5:50:23	how to draw the curve [N]	
5:50:56		i don't know [N]
5:54:38		are you drawing two ideas the red and the green [E]
5:55:50	green is the sun, red is the zig-zag path, what is mean by blue [E]	
5:56:30		blue the vegetation [I] [E]
5:59:05	it seems more balance to put the circle in the centre [N]	
6:00:01		i think the green like the route, but it will be too steep [N]
6:01:21	can green be the steps, red be the ramp, the two curve overlap each other [N]	
6:01:58		ok [N]
6:02:41		the leave over space could be the playground [N]
6:02:57	purple is the seating area, can you draw some vegetation in dark green colour [I] [N]	
6:03:53		ok [N]
6:04:22		i think the blue area 'a' will be the playground [I] [N]
6:05:13		because it away from the hospital
6:05:35	o.k. [N]	
6:10:43		do you agree that the vegetation in irragulation arrangment on the leave over area [N]

Time	Participant 1	Participant 2
6:12:49	I would like the vegetation to follow the orthogonal grid and the contour, it will be very interesting [N]	
6:13:34		yes i agree with you [N]
6:19:41	do us undelete, it will undelete all things [C]	
6:20:13		i did not use undelete before [C] [I]
6:20:19	Don't use undelete, we have 6 minutes left [C]	
6:20:25		ok
6:20:33	i use before, i just remind you [C] [I]	
6:25:13	I WANT TO DRAW THE CURVE RAMP, COULD YOU STOP DRAWING FOR A MOMENT [N]	
6:26:06	O.K. please complete with the orthogonal trees [N]	



Design process

Codes used:

- T task specific
- I interface specific
- H high level design
- L low level design

Time	Participant 1	Participant 2
5:33:36	hello, daniel	
5:33:54	give me a message and then we start	
5:34:01		ok
5:36:13	have you finish reading the program	
5:36:19		not yet
5:38:20	I have the following concept:	
5:38:33		ok i have finished reading
5:38:45	the site is very steep, the path should be zig-zag [H]	
5:39:13		yes
5:39:30		i have some question
5:40:01		what is the meaning of '%' on the item max angle [T]
5:41:03	The % is the same to 1:2, 1:3, etc.curvilinear landscape and path can be form to soften the orthogonal grid of the building [T]	

Time	Participant 1	Participant 2
5:41:40		is '%' mean angle degree [T]
5:42:09	yes, $1/2=50\%$ $1/3=33\%$ , etc	
5:42:17		ok i see
5:42:27		ok let's start
5:43:09		should we start from the design of routes [H]
5:43:12	do you agree to put seating area and playground in central part of the site [H]	
5:44:06		ok. But why should it at the central [H]
5:44:34	easily accessible from three streets [H]	
5:45:16		is would also be at the central but near the east [H]
5:45:30	yes	
5:46:21	point no.1,2 is directly related to point no.6. could we use some curve to direct the flow and create sense of arrival [H]	
5:47:06		ok
5:47:09	the playground should be circle [H]	
5:47:23		could be
5:47:41		where should be the car park space
5:48:16	exiting car park is in the middle road [T]	
5:48:46		ok sorry
5:50:23	how to draw the curve [I]	

Time	Participant 1	Participant 2
5:50:56		i don't know
5:54:38		are you drawing two ideas the red and the green [L]
5:55:50	green is the sun, red is the zig-zag path, what is mean by blue [L]	
5:56:30		blue the vegetation [L]
5:59:05	it seems more balance to put the circle in the centre [H]	
6:00:01		i think the green like the route, but it will be too steep [H]
6:01:21	can green be the steps, red be the ramp, the two curve overlap each other [H]	
6:01:58		ok
6:02:41		the leave over space could be the playground [H]
6:02:57	purple is the seating area, can you draw some vegetation in dark green colour [L]	
6:03:53		ok
6:04:22		i think the blue area 'a' will be the playground [H]
6:05:13		because it away from the hospital
6:05:35	o.k.	
6:10:43		do you agree that the vegetation in irragation arrangment on the leave over area [H]
6:12:49	I would like the vegetation to follow the orthogonal grid and the contour, it will be very interesting	



Time	Participant 1	Participant 2
	[H]	
6:13:34		yes i agree with you
6:19:41	do us undelete, it will undelete all things [I]	
6:20:13		i did not use undelete before [I]
6:20:19	dont' use undelete, we have 6 minutes left [I]	
6:20:25		ok
6:20:33	i use before, i just remind you	
6:25:13	I WANT TO DRAW THE CURVE RAMP, COULD YOU STOP DRAWING FOR A MOMENT [L]	
6:26:06	O.K. please complete with the orthogonal trees [L]	

## References

- Abarbanel, R. M., Brechner, E. & McNeeley, W. (1997) Flythru the Boeing 777. In *Preprints Formal Aspects of Collaborative CAD*, ed. M. L. Maher, J. S. Gero & F. Sudweeks, pp. 3-9. Sydney: Key Centre of Design Computing, Department of Architectural and Design Science, University of Sydney
- Abel, M. J. (1990) Experiences in an exploratory distributed organization. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egidio, pp. 489-510. Hillsdale, NJ: Lawrence Erlbaum Associates
- Alexander, C. (1968) *A Pattern Language Which Generates Multi-Service Centers*. Berkeley, Calif.: Center for Environmental Structure
- Allbriton, R. & Smith, A. (1996) Strengthening partnering behaviour. *DI Quarterly*
- American Institute of Architects. (1975) *Handbook of Professional Practice*. Washington DC: American Institute of Architects Press
- Ancona, D. G. & Caldwell, D. F. (1990) Information technology and work groups: The case of new product teams. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egidio, pp. 173-90. Hillsdale, NJ: Lawrence Erlbaum Associates

- Anthony, K. A. (1991) *Design Juries on Trial: The Renaissance of the Design Studio*. New York: Van Nostrand Reinhold
- Argyris, C. & Schön, D. A. (1974) *Theory in Practice: Increasing Professional Effectiveness*. San Francisco: Jossey Bass
- Arnheim, R. (1996) Sketching and the psychology of design. In *The Idea of Design*, ed. V. Margolin & R. Buchanan, pp. 70-4. Cambridge MA: MIT Press
- Aronson, S. A. (1977) Bell's electrical toy: What's the use? The sociology of early telephone usage. In *MIT Bicentennial Studies*, ed. I. d. S. Pool, pp. 15-39. Cambridge MA: MIT Press
- Bazjanac, V. (1974) Architectural design theory: Models of the design process. In *Basic Questions of Design Theory*, ed. W. R. Spillers, pp. 3-19. New York: American Elsevier Publishing Co. Inc.
- Bedard, J. & Chi, M. (1992) Expertise. *Directions in Psychological Science*, 1(1), 135-9
- Bentley Systems. (1998) Modelserver Publisher. [Http://www.bentley.com/modelserver/](http://www.bentley.com/modelserver/). 080798
- Bhavnani, S. K. & John, B. E. (1997) From sufficient to efficient usage: An analysis of strategic knowledge. CHI '97, 22-27 March
- Bikson, T. K. & Eveland, J. D. (1990) The interplay of work group structures and computer support. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egido, pp. 245-90. Hillsdale, NJ: Lawrence Erlbaum Associates
- Blackmore, C. (1990) *The Client's Tale*. London: RIBA Publications
- Blau, J. (1984) *Architects and Firms: A Sociological Perspective on Architectural Practice*. Cambridge MA: MIT Press
- Bly, S. A., Harrison, S. R. & Irwin, S. (1993) Media Spaces: Bringing people together in a video, audio and computing environment. *Communications of the ACM*, 36(1), January, 28-47
- Bly, S. A. & Minneman, S. L. (1990) Commune: A shared office surface. In *Proceedings of the Conference on Office Information Systems*. Conference on Office Information Systems, pp. 184-92. Boston
- Bouhuijs, P. A. J., Schmidt, H. & van Berkel, H., ed. (1993) *Problem-Based Learning as an Educational Strategy*. Maastricht: Network Publications



- Bozdogan, S. (1989) Research roundtable: Excellence in design and practice. In *In Search of Excellence*, ed. T. Vonier, pp. 139-51. Washington DC: American Institute of Architects Press
- Bradford, J. W., Cheng, N. & Kvan, T. (1994) Virtual Design Studios. In *The Virtual Studio*, ed. T. Maver & J. Petric. ECAADe '94, pp. 163-7. University of Strathclyde, Glasgow: ECAADe
- Bridges, A. & Charitos, D. (1997) On architectural design in virtual environments. *Design Studies*, 18, 143-54
- Brown, F. E., Cooper, G. S., Ford, S., Aouad, G., Brandon, P., Child, T., Kirkham, J. A., Oxman, R. & Young, B. (1995) An integrated approach to CAD: Modelling concepts in building design and construction. *Design Studies*, 16, 327-47
- Bruffee, K. A. (1993) *Collaborative Learning: Higher Education, Interdependence and the Authority of Knowledge*. Baltimore: The John Hopkins University Press
- Buchanan, R. (1995) Wicked problems in design thinking. In *The Idea of Design*, ed. V. Margolin & R. Buchanan, pp. 3-20. Cambridge MA: MIT Press
- Burgoon, J. K. (1994) Nonverbal signals. In *Handbook of Interpersonal Communication, 2nd Edition*, ed. M. L. Knapp & G. R. Miller, pp. 229-85. Thousand Oaks: SAGE Publications Inc.
- Cabellos, C., Casaus, A., Fargas, J., Mas, M., Papazian, P. & Roses, J. (1994) Heterogenous, distributed, collaborative: The Li-Long virtual design studio. In *The Virtual Studio*, ed. T. Maver & J. Petric. ECAADe '94, pp. 175-82. University of Strathclyde, Glasgow: ECAADe
- CADD Layer Guidelines* (1990), ed. M. Schley. Washington DC: American Institute of Architects Press
- Candy, L. & Edmonds, E. A. (1977) Supporting the creative user: A criteria-based approach to interaction design. *Design Studies*, 18, 185-94
- Caneparo, L. (1995) Coordinative virtual space for architectural design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 739-48. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Chafe, W. L. (1982) Integration and involvement in speaking, writing and oral literature. In *Spoken and Written Language: Exploring Orality and Literacy*, ed. D. Tannen, pp. 35-53. Norwood, NJ: ALEX Publishing Corporation

- Chandrasekaran, B. (1990) Design Problem solving: A task analysis. *AI Magazine*, Winter, 59-71
- Chappell, D. & Willis, C. J. (1992) *The Architect in Practice*, 7th edn. London: Blackwell Scientific Publications
- Charlton, K. (1973) The education of the professions in the sixteenth century. In *Education and the Professions*, ed. T. G. Cook, pp. 19-27. London: Methuen & Co Ltd
- Chase, W. G. & Ericsson, K. A. (1982) Skill and working memory. In *The Psychology of Learning and Motivation*, ed. G. H. Bower, pp. 1 - 58. New York: Academic Press
- Chase, W. G. & Simon, H. A. (1973) The mind's eye in chess. In *Visual Information Processing*, ed. W. G. Chase, pp. 215 - 281. New York: Academic Press
- Cheng, N. Y. W. (1998) Wayfinding in Cyberspace. In *Proceedings of the Third Conference on Computer-Aided Architectural Design Research in Asia*, ed. T. Sasada, S. Yamaguchi, M. Morozumi, A. Kaga & R. Homma. CAADRIA '98, pp. 83-92. Osaka: CAADRIA, Morozumi & Iki Laboratory, Department of Architecture and Civil Engineering, Faculty of Engineering, Kumamoto University, 22-24 April
- Cheng, N., Kvan, T., Wojtowicz, J., vanBakergem, D., Casaus, T., Davidson, J., Fargas, J., Hubbell, K., Mitchell, W. J., Nagakura, T. & Papazian, P. (1994) Place Time and The Virtual Design Studio. In *Reconnecting*, ed. A. Harfmann & M. Fraser. ACADIA, pp. 115-31. Washington University, St. Louis: ACADIA
- Chiu, M.-I. (1995) Collaborative design in CAAD studios: Shared ideas, resources and representations. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 749-59. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Chiu, M.-I. (1997) The design guidance of CSCW. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 261-70. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Chung, W. C. (1997) Designing by wire. *Design Management Journal*, Summer, 64-70
- Churchman, C. W. (1967) Wicked problems. *Management Science*, 14(4), December, B141-2



- Clancey, W. J. (1997) *Situated Cognition : On Human Knowledge and Computer Representations*. Cambridge: Cambridge University Press
- Clark, H. H. & Brennan, S. E. (1991) Grounding in communication. In *Perspectives on Socially Shared Cognition*, ed. L. B. Resnick, J. M. Levine & S. D. Teasley, pp. 127-49. Washington DC: American Psychological Association
- Comair, C., Kaga, A. & Sasada, T. (1996) Collaborative design system with network technologies in design projects. In *The Introduction of Technology*, ed. T. Kvan. CAADRIA '96, pp. 267-86. Hong Kong: Department of Architecture, University of Hong Kong
- Cowdroy, R. & Maitland, B. (1994) Integration, assessment and problem based learning. In *Reflections on Problems Based Learning*, ed. S. E. Chen, R. Cowdroy, A. Kingsland & M. Ostwald, pp. 175-87. Campbelltown, NSW: Australian Problem Based Learning Network
- Coxe, W. (1989) Role models of excellence: Learnings from the research roundtable. In *In Search of Design Excellence*, ed. T. Vonier, pp. 91-114. Washington: American Institute of Architects Press
- Coxe, W., Hartung, N. F., Hochberg, H. H., Lewis, B. J., Maister, D. H., Mattox, R. F. & Piven, P. A. (1987) *Success Strategies for Design Professionals*. New York: McGraw Hill
- Coyne, R. D., McLaughlin, S. & Newton, S. (1996) Information technology and praxis: A survey of computers in design practice. *Environment and Planning B: Planning and Design*, 23, 515-51
- Coyne, R. D., Sudweeks, F. & Haynes, D. (1996) Who needs the Internet? Computer-mediated communication in design firms. *Environment and Planning B: Planning and Design*, 23, 749-70
- Cross, N. & Cross, A. C. (1995) Observations of teamwork and social processes in design. *Design Studies*, 16, 143-70
- Cuff, D. (1989) The origins of excellent buildings. In *In Search of Design Excellence*, ed. T. Vonier, pp. 77-89. Washington: American Institute of Architects Press
- Cuff, D. (1991) *Architecture: The Story of Practice*. Cambridge, MA: MIT Press
- Danahy, J. W. & Hoinkes, R. (1995) Polytrim: Collaborative setting for environmental design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures, pp. 647-58. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, 24-26 September



- Dave, B. (1995) Towards distributed computer-aided design environments. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 659-66. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Day, J. (1993) Paperless practices. *Architecture*, October, 89-95
- Dennis, A. R., George, J. F., Jessup, L. M., Nunamaker, J. F. & Vogel, D. R. (1988) Information Technology to Support Electronic Meetings. *MIS Quarterly*, 12, 591-618
- Dewey, J. (1896) The reflex arc concept in psychology. *Psychological Review*, 3 (reprinted 1981), 357-70. Quoted in Gero 1998
- Dhar, V. & Olson, M. H. (1989) Assumptions underlying systems that support work group collaboration. In *Technological Support for Work Group Collaboration*, ed. M. H. Olson, pp. 33-50. Hillsdale, NJ: Lawrence Erlbaum Associates
- Dobson, A., Dokonal, W. & Kosco, I. (1995) World wide web presentation of collaborative student design work. In *Multimedia and Architectural Disciplines*, ed. B. Colajanni & G. Pellitteri. ECAADe '95, pp. 105-9. Palermo: ECAADe, 16-18 November
- Donald, M. (1991) *Origins of the Modern Mind: Three Stages in the Evolution of Culture and Cognition*. Cambridge MA: Harvard University Press
- Dorst, K. (1996) The design problem and its structure. In *Analysing Design Activity*, ed. N. Cross, H. Christiaans & K. Dorst, pp. 17-34. Chichester: John Wiley & Sons Ltd.
- Dorst, K. & Dijkhuis, J. (1995) Comparing paradigms for describing design activity. *Design Studies*, 16, 261-74
- Dreyfus, H. L. & Dreyfus, S. E. (1986) *Mind Overmachine: The Power of Human Intuition and Expertise in the Era of the Computer*. Oxford: Basil Blackwell
- Eason, K. & Olphert, W. (1996) Early evaluation of the organisational implications of CSCW systems. In *CSCW Requirements and Evaluation*, ed. P. J. Thomas, pp. 75-89. London: Springer-Verlag
- Easterbrook, S. M. (1993) *CSCW: Cooperation or Conflict*. Computer Supported Cooperative Work. London: Springer-Verlag

- Easterbrook, S. M. (1996) Coordination breakdowns: How flexible is collaborative work? In *CSCW Requirements and Evaluation*, ed. P. J. Thomas, pp. 92-106. London: Springer-Verlag
- Easterbrook, S. M., Beck, E. E., Goodlet J. S., Plowman, L., Sharples, M. & Wood C. C. (1993) A survey of empirical studies of conflict. In *CSCW: Cooperation or Conflict*, ed. S. M. Easterbrook, pp. 1-68. London: Springer-Verlag
- Emprin, G., Giroto, E., Gotta, A., Livi, T. & Priore, M. L. (1997) Virtual studio of design and technology on Internet (II). In *Challenges of the Future*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97, pp. CD-ROM version, 8 pages. Vienna: Österreichischer Kunst- und Kulturverlag, 17-20 September
- Eraut, M. (1994) *Developing Professional Knowledge and Competence*. London: The Falmer Press
- Ettorre, B. (1995) Corporate real estate: Building a strategic new world. *Management Review*, 84(2), February, 43-7
- Favela, J., Imai, K. & Connor, J. J. (1994) Hypermedia support for collaborative design. *Design Studies*, 15(1), 45-58
- Finholt, T. & Sproull, L. S. (1990) Electronic groups at work. *Organizational Science*, 1, 41-64
- Finn, K. E. (1997) Introduction: An overview of video-mediated communication literature. In *Video-Mediated Communication*, ed. K. E. Finn, A. J. Sellen & S. B. Wilbur, pp. 3-21. Mahwah, NJ: Lawrence Erlbaum Associates
- Fitzpatrick, G., Kaplan, S. & Mansfield, T. (1996) Physical spaces, virtual places and social worlds. In *Proceedings of the ACM 1996 Conference on Computer Supported Cooperative Work*, ed. M. S. Ackerman. CSCW '96, pp. 334-43. New York: ACM Press, November
- Flemming, U., Bhavnani, S. K. & John, B. E. (1997) Mismatched metaphor: User vs system model in computer-aided drafting. *Design Studies*, 18, 349-68
- Franklin, J. (1989) Keys to design excellence: Learnings from the AIA 1989 design practice for the 90s program. In *In Search of Design Excellence*, ed. T. Vonier, pp. 1-56. Washington: American Institute of Architects Press
- Franklin, J. (1993) Ruminations of a CAD victim. *Progressive Architecture*, April, 59-60
- Freyd, J. J. (1994) Circling creativity. *Psychological Science*, 5(3), May, 122-6



- Fruchter, R. (1996) Conceptual, collaborative building design through shared graphics. *IEEE Expert*, 11(3), June, 33-41
- Fruchter, R., Clayton, M. J., Krawinkler, H., Kunz, J. & Teicholz, P. (1996) Interdisciplinary communication medium for collaborative conceptual building design. *Advances in Engineering Software*, 25, 89-101
- Fuchs, W. & Martino, A. (1996) The v.C.net - a digital study in architecture. In *Design Computation: Collaboration, Reasoning, Pedagogy*, ed. P. McIntosh & F. Ozel. ACADIA '96, pp. 23-9. University of Arizona: ACADIA, 31 October - 2 November
- Fukuda, T., Nagahama, R. & Sasada, T. (1997) Collaboration support system for public design. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 299-307. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Galegher, J. & Kraut, R. E. (1990) Technology for intellectual teamwork: Perspectives on research and design. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egido, pp. 1-20. Hillsdale, NJ: Lawrence Erlbaum Associates
- Gallupe, R. B., Bastianutti, L. M. & Cooper, W. H. (1991) Unblocking Brainstorms. *Journal of Applied Psychology*, 76, 137-42
- Gallupe, R. B. & DeSanctis, G. (1988) Computer-Based Support for Group Problem-Finding: An Experimental Investigation. *MIS Quarterly*, 12, 277-96
- Gero, J. S. (1998) Conceptual designing as a sequence of situated acts. In *Lecture Notes in Artificial Intelligence 1454*, ed. I. Smith. Structural Engineering Applications of Artificial Intelligence Workshop, pp. 165-77. Springer-Verlag, July
- Gero, J. S. & McNeill, T. (1998) An approach to the analysis of design protocols. *Design Studies*, 19, 21-61
- Gibson, J. J. (1979) *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin
- Giedion, S. (1941) *Space, Time and Architecture : The Growth of a New Tradition*. Cambridge MA: Harvard University Press
- Giles, H. & Street, R. L. (1994) Communicator characteristics and behavior. In *Handbook of Interpersonal Communication, 2nd Edition*, ed. M. L. Knapp & G. R. Miller, pp. 103-61. Thousand Oaks: SAGE Publications Inc.



- Goel, V. (1995) *Sketches of Thought*. Cambridge, MA: MIT Press
- Goel, V. & Pirolli, P. (1992) The structure of problem spaces. *Cognitive Science*, 16(3), 395-429
- Goldschmidt, G. (1991) The dialectics of sketching. *Creativity Research Journal*, 4, 123-43
- Goldschmidt, G. (1994) On visual design thinking: The vis kids of architecture. *Design Studies*, 15(2), 158-74
- Goode, L. & Scarponcini, P. (1997) Microstation continuum: Unified data storage in a spatially extended RDBMS. [Http://www.bentley.com/products/continuum/white/continum.doc](http://www.bentley.com/products/continuum/white/continum.doc), 12 April. 08/07/98
- Grant, M. (1997) CREDIT - Collaborative Research in Education for Designers using IT. In *Challenges of the Future*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97, pp. CD-ROM version. Vienna: Österreichischer Kunst- und Kulturverlag, 17-20 September
- Greenberg, S. (1991) Computer-supported cooperative work and groupware: An introduction to the special issues. *International Journal of Man-Machine Studies*, 34, 133-41
- Grenier, R. & Metes, G. (1992) *Enterprise Networking: Working Together Apart*. Bedford MA: Digital Press
- Grootel, M. v. (1994) LAVA: A virtual studio on the Internet. In *The Virtual Studio*, ed. T. Maver & J. Petric. ECAADe '94, pp. 168-74. University of Strathclyde, Glasgow: ECAADe
- Grønbaek, K., Kyng, M. & Mogenssen, P. (1993) CSCW challenges: Cooperative design in engineering projects. *Communications of the ACM*, 36(4), 67-77
- Gutman, R. (1988) *Architectural Practice : A Critical View*. New York, NY: Princeton Architectural Press
- Hammer, M. (1990) Reengineering work: Don't automate, obliterate. *Harvard Business Review*, July-August, 104-12
- Hammond, K. R. (1980) *Human Judgment and Decision Making : Theories, Methods, and Procedures*. New York: Praeger
- Harré, R. (1993) *Social Being (Second Edition)*. Oxford: Blackwell

- Harrison, S., Bly, S. A., Anderson, S. & Minneman, S. L. (1997) The media space. In *Video-Mediated Communication*, ed. K. E. Finn, A. J. Sellen & S. B. Wilbur, pp. 273-300. Mahwah, NJ: Lawrence Erlbaum Associates
- Harrison, S. & Minneman, S. L. (1990) The media space: A research project into the use of video as a design medium. In *Readings in Groupware and Computer-Supported Cooperative Work*, 1993, ed. R. Baecker, pp. 785-91. San Mateo: Morgan Kaufman Publishers
- Harrison, S. & Minneman, S. L. (1995) Studying collaborative design to build design tools. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 687-97. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Hastie, R. & Pennington, N. (1991) Cognitive and social processes in decision making. In *Perspectives on Socially Shared Cognition*, ed. L. B. Resnick, J. M. Levine & S. D. Teasley, pp. 308-27. Washington DC: American Psychological Association
- Hayes, J. R. (1985) Three problems in teaching general skills. In *Thinking and Learning Skills, Volume 2, Research and Open Questions*, ed. S. F. Chipman, J. W. Segal & R. Glaser, pp. 391-405. Hillsdale NJ: Lawrence Erlbaum Associates
- Hildyard, A. & Olson, D. R. (1982) On the comprehension and memory of oral vs. written discourse. In *Spoken and Written Language: Exploring Orality and Literacy*, ed. D. Tannen, pp. 19-33. Norwood, NJ: ALEX Publishing Corporation
- Hollan, J. & Stornetta, S. (1993) Beyond Being There. In *Readings in Groupware and Computer-Supported Cooperative Work*, ed. R. Baecker. San Mateo: Morgan Kaufman Publishers
- Holtham, C. (1994) Groupware: Its past and future. In *Groupware in the 21st Century : Computer Supported Cooperative Working Toward the Millennium*, ed. P. Lloyd, pp. 3-14. Westport, Connecticut: Praeger
- Hutchins, E. (1990) The technology of team navigation. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egidio, pp. 191-220. Hillsdale NJ: Lawrence Erlbaum Associates
- Hutchins, E. (1991) The social organisation of distributed cognition. In *Perspectives on Socially Shared Cognition*, ed. L. B. Resnick, J. M. Levine & S. D. Teasley, pp. 283-307. Washington DC: American Psychological Association



- Illich, I. D. (1971) *Deschooling Society*. London: Calder and Boyars
- Jabi, W. & Hall, T. W. (1995) Beyond the shared whiteboard: Issues in computer supported collaborative design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 719-25. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Jablin, F. M. & Krone, K. J. (1994) Task/work relationships: A life-span perspective. In *Handbook of Interpersonal Communication, 2nd Edition*, ed. M. L. Knapp & G. R. Miller, pp. 621-75. Thousand Oaks: SAGE Publications Inc.
- Jarvenpaa, S. L., Rao, V. S. & Huber, G. P. (1988) Computer support for meetings of groups working on unstructured problems: A field experiment. *MIS Quarterly*, 12, 645-65
- Jeng, T.-s. & Eastman, C. M. (1998) A database architecture for design collaboration. *Automation in Construction*, 7(6), 475-83
- Johansen, R. (1989) User approaches to computer-supported teams. In *Technological Support for Work Group Collaboration*, ed. M. H. Olson, pp. 1-31. Hillsdale, NJ: Lawrence Erlbaum Associates
- Jones, J., Christopher. (1966a) Design methods compared: Strategies. *Design*, 212 (August), 32-5
- Jones, J., Christopher. (1966b) Design methods compared: Tactics. *Design*, 213 (September), 46-52
- Kaga, A., Comair, C. & Sasada, T. (1997) Collaborative design system with network technologies. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 187-96. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Kalay, Y. E. (1997) P3: An integrated environment to support design collaboration. In *Representation & Design*, ed. J. P. Jordan, B. Mehnert & A. Harfmann. ACADIA'97, pp. 192-205. Cincinnati: ACADIA, 3-5 October
- Kalay, Y. E. & Séquin, C. (1995) Designer-Client relationships in architectural and software design. In *Computing in Design*, ed. L. N. Kalisperis & B. Kolarevic. ACADIA '95, pp. 383-403. ACADIA
- Kalisperis, L. N. & Groninger, R. L. (1994) CADD utilization in the architectural design process: Implications for computer integration in practice. *Journal of Architectural and Planning Research*, 11(2), Summer, 137-48



- Kaye, A. (1992) Learning together apart. In *Collaborative Learning Through Computer Conferencing: The Najaden Papers*, ed. A. Kaye, pp. 1-24. New York: Springer-Verlag
- Kemper, A. M. (1985) *Pioneers of CAD*. Pacifica, California: Hurland/Swenson Publishers
- Khedro, T. (1995) AgentCAD for cooperative design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures, pp. 667-72. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, 24-26 September
- Kidder, T. (1985) *House*. Boston: Houghton Mifflin
- Kiesler, S. & Sproull, L. S. (1992) Group decision making and communication technology. *Organizational Behavior and Human Decision Processes*, 52, 96-123
- Kim, I., Liebich, T., & Maver, T. (1997) Managing design data in an integrated CAAD environment: A product model approach. *Automation in Construction*, 7, 35-53
- Kimura, T., Komatsu, K. & Watanabe, H. (1995) Spatial configuration data model for inter-application collaborative design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 761-70. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Klahr, D. (1998) Preview of paper, to appear in Bulletin of the Japanese Cognitive Science Society, Personal e-mail received 18 September
- Knapp, R. W. & McCall, R. (1996) PHIDAS II - In support of collaborative design. In *Design Computation: Collaboration, Reasoning, Pedagogy*, ed. P. McIntosh & F. Ozel. ACADIA '96, pp. 147-54. University of Arizona: ACADIA, 31 October - 2 November
- Koschmann, T. D., Myers, A. C., Feltovich, P. J. & Barrows, H. S. (1994) Using technology to assist in realizing effective learning and instruction: A principled approach to the use of computers in collaborative learning. *The Journal of the Learning Sciences*, 3(3), 227-64
- Kostoff, S. (1977) *The Architect*. Oxford: Oxford University Press
- Kraemer, K. L. & Pinsonneault, A. (1990) Technology and groups: Assessment of the empirical research. In *Intellectual Teamwork: Social and Technological Foundations of Cooperative Work*, ed. J. Galegher, R. E. Kraut & C. Egido, pp. 375-405. Hillsdale, NJ: Lawrence Erlbaum Associates

- Kraut, R. E., Galegher, J. & Egidio, C. (1987-88) Relationships and tasks in scientific research collaborations. *Human Computer Interaction*, 3, 31-58
- Kraut, R. E., Miller, M. D. & Siegel, J. (1996) Collaboration in performance of physical tasks: Effects on outcomes and communication. In *Proceedings of the ACM 1996 Conference on Computer Supported Cooperative Work*, ed. M. S. Ackerman. CSCW '96, pp. 57-66. New York: ACM Press, November
- Kuhn, T. (1970) *The Structure of Scientific Revolutions*, second edition. Chicago: University of Chicago
- Kurland, T. & Barber, P. (1996) User requirements from a group perspective: The case of distance learning mediated by computer conferencing. In *CSCW Requirements and Evaluation*, ed. P. J. Thomas, pp. 57-74. London: Springer-Verlag
- Kusama, H., Fukuda, T., Park, J. W., & Sasada, T. (1996) Networked CAD system for designer group. In *The Introduction of Technology*, ed. T. Kvan. CAADRIA '96, pp. 153-61. Hong Kong: Department of Architecture, University of Hong Kong
- Kvan, T. (1994) Reflections on computer mediated architectural design. *IEEE Transactions on Professional Communication*, 37(4), 226-30
- Kvan, T. (1995) Fruitful exchanges: Professional implications for computer-mediated design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 771-6. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Kvan, T. (1996) Design services in the era of the Web. *Design Intelligence*, 2 (16 February), 1-3
- Kvan, T., Keynote speaker. (1997a) But is it collaboration. In *Challenges of the Future*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97, p. 5. Vienna: Österreichischer Kunst- und Kulturverlag
- Kvan, T. (1997b) The evolving story: Computers, architecture and education. *Dialogue*, 5 (October)
- Kvan, T. (1997c) Studio teaching without meeting: Pedagogical aspects of a Virtual Design Studio. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 163-77. Taipei: Hu's Publisher Inc.



- Kvan, T. (1998) Collaborative design communication: The Internet as a project management tool. *Design Intelligence*, 4(17), 15 September, 3-5
- Kvan, T., Vera, A. & West, R. (1997) Expert and situated actions in collaborative design. In *Proceedings of Second International Workshop on CSCW in Design*, ed. P. Siriruchatapong, Z. Lin & J.-P. Barthes. Second International Workshop on CSCW in Design, pp. 400-5. Beijing: International Academic Publishers, November
- Kvan, T., West, R. & Vera, A. (1997) Tools for a Virtual Design Community. In *Preprints Formal Aspects of Collaborative CAD*, ed. M. L. Maher, J. S. Gero & F. Sudweeks, pp. 109-23. Sydney: Key Centre of Design Computing, Department of Architectural and Design Science, University of Sydney
- Kvan, T., West, R. & Vera, A. (1998) Tools and Channels of Communication: Dealing with the Effects of Computer Mediation on Design Communication. [Http://www.ijvr.com/ijvr/articles/list.htm](http://www.ijvr.com/ijvr/articles/list.htm). *International Journal of Virtual Reality*, 3(3)
- L'Henry-Evans, O. (1974) Teaching by telephone: Some practical observations. *Teaching at a Distance*, 1 (November), 67-9. Milton Keynes: Open University
- Laiserin, J. A. (1996) Information technology and architectural practice: The state of the art. *ACADIA Quarterly*, 15(3), Summer, 13-9
- Larkin, J. H. & Simon, H. A. (1987) Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science*, 11, 65-100
- Larson, E. (1997) Partnering on construction projects: A study of the relationship between partnering activities and project success. *IEEE Transactions on Engineering Management*, 44(2), May, 188-95
- Latour, B. (1987) *Science in Action*. Milton Keynes: Open University Press
- Lawson, B. (1980) *How Designers Think*. London: Architectural Press
- Lawson, B. (1994) *Design in Mind*. Oxford: Butterworth-Heinemann Ltd.
- Lawson, B. & Loke, S. M. (1997) Computers, words and pictures. *Design Studies*, 18, 171-83
- Lee, E., Woo, S., Kim, I. & Sasada, T. (1997) Experimental study in inter-university collaboration. In *15th ECAADE Conference Challenges of the Future, CD-Rom Imprint*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97. Österreichischer Kunst- und Kulturverlag, 17-20 September



- Lewis, B. J., Shea, G. P. & Kvan, T. (1990) Managing change in the design process caused by implementation of CADD in consulting engineering firms. In *Proceedings*. Consulting Engineering Conference. Toronto, October
- Lewis, D. (1972) *We, the Navigators: The Ancient Art of Landfinding in the Pacific*. Canberra: Australian National University Press
- Lin, F.-T. & Wang, H. (1997) A case study of cooperative design using video conference. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 153-62. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Loopy.com? (1998) *The Economist*, 25 July, 69
- Maher, M. L., Cicognani, A. & Simoff, S. J. (1997) An experimental study of computer mediated collaborative design. [Www.arch.usyd.edu.au/kcdc/cmcd/paper](http://www.arch.usyd.edu.au/kcdc/cmcd/paper). *International Journal of Design Computing*, 1. 06/01/97
- Martens, B. & Dokonal, W. (1997) Collaborative Teamwork GRAWI '97: The Third Attempt to "Internet-Design". In *15th ECAADE Conference Challenges of the Future, CD-Rom Imprint*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97. Österreichischer Kunst- und Kulturverlag, 17-20 September
- Martens, B., Voigt, A., Schmidinger, E. & Linzer, H. (1995) The effective use of multimedia and telematics in planning and design. In *Multimedia and Architectural Disciplines*, ed. B. Colajanni & G. Pellitteri. ECAADe '95, pp. 75-82. Palermo: ECAADe, 16-18 November
- Mattessich, P. W. & Monsey, B. R. (1992) *Collaboration: What Makes It Work*. St. Paul, Minnesota: Amherst H. Wilder Foundation
- McCall, R., Bennet, P. & Johnson, E. (1994) An overview of the PHIDAS II hyperCAD system. In *Reconnecting*, ed. A. Harfmann & M. Fraser. ACADIA'94, pp. 63-74. Washington University, St. Louis: ACADIA
- McConnell, D. (1992) Computer mediated communication for management learning. In *Collaborative Learning Through Computer Conferencing: The Najaden Papers*, ed. A. Kaye, pp. 51-68. New York: Springer-Verlag
- McCullough, M. & Hoinkes, R. (1995) Dynamic data sets as collaboration in urban design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD

- Futures '95, pp. 709-18. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- McGrath, J. E. & Hollingshead, A. B. (1994) *Groups Interacting with Technology: Ideas, Evidence, Issues, and an Agenda*. Sage Library of Social Research, vol. 194. Thousand Oaks, CA: SAGE Publications Inc.
- Miller, G. A. (1956) The magic number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97
- Mitchell, W. J. (1977) *Computer-Aided Architectural Design*. New York: Van Nostrand Reinhold
- Mitchell, W. J. (1994) Three paradigms for computer-aided design. *Automation in Construction*, 3, 239-45
- Mitchell, W. J. (1995a) CAD as a social process. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 7-10. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Mitchell, W. J. (1995b) The future of the virtual design studio, In *Virtual Design Studio*, ed. J. Wojtowicz, pp. 51-60. Hong Kong: Hong Kong University Press
- Moran, T. P., Chiu, P., Harrison, S., Kurtenbach, G., Minneman, S. L. & van Melle, W. (1996) Evolutionary engagement in an ongoing collaborative work process. In *Proceedings of the ACM 1996 Conference on Computer Supported Cooperative Work*, ed. M. S. Ackerman. CSCW '96, pp. 150-9. New York: ACM Press, November
- Morozumi, M., Murakami, Y. & Iki, K. (1995) Network based group work CAD for UNIX workstation. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures, pp. 637-46. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, 24-26 September
- Morozumi, M., Takahashi, M., Naka, R., Kawasumi, N., Homma, R., Mitchell, W. J., Yamaguchi, S. & Iki, K. (1997) The levels of communications achieved through network in an international collaborative design project: An analysis of VDS'96 project carried out between Kumamoto University, MIT and Kyoto Institute of Technology. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 143-52. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Morris, J., Rogerson, J. & Jared, G. (1998) A tool for modelling the briefing and design decision making processes in construction. In *Proceedings*.



- ARCOM (Association of Researchers in Construction Management) Fourteenth Annual Conference, pp. 320-9. University of Reading, 9 -11 September
- Muir, T. (1995) Introduction to collaborative practice. In *Collaborative Practice in the Built Environment*, ed. T. Muir & B. Rance, pp. 1-24. London: E&FN Spon
- Murakami, Y., Morozumi, M., Iino, K., Homma, R. & Iki, K. (1997) On the development and the use of group work CAD for Windows-PCs. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 179-86. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Myers, I. B. (1993) *Introduction to Type: A Guide to Understanding Your Results on the Myers-Briggs Type Indicator*, 5th edn., ed. L. K. Kirby & K. D. Myers. Palo Alto, Calif.: Consulting Psychologists Press
- Nardi, B., Kuchinsky, A., Whittaker, S., Leichner, R. & Schwarz, H. (1997) Video-as-data: Technical and social aspects of a collaborative multimedia application. In *Video-Mediated Communication*, ed. K. E. Finn, A. J. Sellen & S. B. Wilbur, pp. 487-517. Mahwah, NJ: Lawrence Erlbaum Associates
- Newell, A. & Simon, H. A. (1972) *Human Problem Solving*. Englewood Cliffs, NJ: Prentice-Hall
- Norman, D. A. (1993) Cognition in the head and in the world: An introduction to the special issue on situated action. *Cognitive Science*, 17, 1-6
- Novitski, B. J. (1994) Linking up the building team. *Architecture*, September, 129-31
- Novitski, B. J. (1996) Telecommuting design: Merging virtual technologies change the rules of collaboration. *Architectural Record*, October, 46-51
- Nunamaker, J. F., Briggs, R. O. & Mittleman, D. D. (1995) Electronic meeting systems: Ten years of lessons learned. In *Groupware: Technology and Applications*, ed. D. Coleman & R. Khanna. New York: Prentice-Hall
- O'Doherty, E. F. (1976) *Social Psychology*. Human Psychology, vol. 2. Dublin: Department of Psychology, University College
- Olley, H. (1992) *1990 Profile of the Architectural Profession*. Canberra: Royal Australian Institute of Architects, National Division



- Olson, D. R. (1996) Towards a psychology of literacy: On the relations between speech and writing. *Cognition*, 60, 83-104
- Olson, G. M. (1994) Situated cognition. In *Encyclopedia of Human Intelligence*, ed. R. J. Sternberg, pp. 971-3. New York: Macmillan
- Olson, G. M. & Olson, J. S. (1991) User-centred design of collaboration technology. *Journal of Organizational Computing*, 1, 61-83
- Olson, G. M., Olson, J. S., Carter, M. R. & Storösten, M. (1992) Small group meetings: An analysis of collaboration. *Human Computer Interaction*, 7, 347-74
- Olson, G. M., Olson, J. S., Storösten, M., Carter, M. R., Herbsleb, J. & Rueter, H. (1996) Structure of activity during design meetings. In *Design Rationale: Concepts, Techniques and Use*, ed. T. P. Moran & J. M. Carroll, pp. 217-40. Hillsdale, NJ: Lawrence Erlbaum Associates
- Olson, J. S., Olson, G. M. & Meader, D. (1997) Face-to-face group work compared to remote group work with and without video. In *Video-Mediated Communication*, ed. K. E. Finn, A. J. Sellen & S. B. Wilbur, pp. 157-72. Mahwah, NJ: Lawrence Erlbaum Associates
- Ostwald, M. & Chen, S. E. (1994) Marginalisation of theoretical issues in a professional PBL course - a structural or attitudinal problem. In *Reflections on Problems Based Learning*, ed. S. E. Chen, R. Cowdroy, A. Kingsland & M. Ostwald, pp. 87-104. Campbelltown, NSW: Australian Problem Based Learning Network
- Peng, C. (1994) Exploring communication in collaborative design: Co-operative architectural modelling. *Design Studies*, 15(1), January, 19-44
- Peña, W. (1977) *Problem Seeking : An Architectural Programming Primer*. Boston: Cahnern Books International
- Perkin, H. (1973) The professionalization of university teaching. In *Education and the Professions*, ed. T. G. Cook, pp. 69-84. London: Methuen & Co Ltd
- Phair, M. (1996) Networks to end CAD isolation. *Engineering News Record*, 18 November, 32
- Phair, M. & Angelo, W. J. (1997) Digital demands. *Engineering News Record*, 24 March, 30-6
- Piven, P. A. (1996) Increasing Your Project Team's Effectiveness. *Design Intelligence*, 2(10), 10 June, 1-3

- Pool, I. d. S., Decker, C., Dizard, S., Israel, K., Rubin, P. & Weinstein, B. (1977) Foresight and hindsight; the case of the telephone. In *MIT Bicentennial Studies*, ed. I. d. S. Pool, pp. 127-57. Cambridge MA: MIT Press
- Portillo, M. & Dohr, J. H. (1994) Bridging process and structure through criteria. *Design Studies*, 15(4), 403-16
- Purcell, A. T. & Gero, J. S. (1998) Drawings and the design process. *Design Studies*, 19, 389-430
- Purcell, A. T., Gero, J. S., Edwards, H. & McNeill, T. (1996) The Data in Design Protocols: The Issue of Data Coding, Data Analysis in the Development of Models of the Design Process. In *Analysing Design Activity*, ed. N. Cross, H. Christiaans & K. Dorst, pp. 225-52. Chichester: Wiley
- Rand, A. (1943) *The Fountainhead*. Indianapolis: The Bobbs-Merrill Company
- Reid, A. A. L. (1977) Comparing telephone with face-to-face contact. In *The Social Impact of the Telephone*, ed. I. d. S. Pool, pp. 386-414. Cambridge, MA: MIT Press
- Reitman, W. R. (1964) Heuristic decision procedures, open constraints, and the structure of ill-defined problems. In *Human Judgements and Optimality*, ed. M. W. Shelly & G. L. Bryan. New York: John Wiley and Sons
- Richens, P. (1990) *MicroCAD Software Evaluated*, second edition. Cambridge: Construction Industry Computing Association
- Rittel, H. W. J. (1972) Son of Rittelthink. Design Methods Group 5th Anniversary Report. Design Methods Group Occasional Papers, vol. 1, January
- Rittel, H. W. J. & Webber, M. (1973) Dilemma in a general theory of planning. *Policy Sciences*, 4, 155-60
- Robbins, E. (1994) *Why Architects Draw*. Cambridge, MA: MIT Press
- Ross, S. S. (1997) Collaboration by wire. *Architectural Record*, September, 131-7
- Rowe, P. G. (1987) *Design Thinking*. Cambridge MA: MIT Press
- Rueschemeyer, D. (1983) Professional autonomy and the social control of expertise. In *The Sociology of the Professions: Lawyers, Doctors and Others*, ed. R. Dingwall & P. Lewis, pp. 13-34. London: The Falmer Press
- Russell, A., Creedy, D. & Davis, J. (1994) The use of contract learning in PBL. In *Reflections on Problems Based Learning*, ed. S. E. Chen, R. Cowdroy, A.



- Kingsland & M. Ostwald, pp. 57-72. Campbelltown, NSW: Australian Problem Based Learning Network
- Rutherford, J. (1995) A multi-user design workspace. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures, pp. 673-85. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, 24-26 September
- Saad, M. & Maher, M. L. (1995) Exploring the possibilities for computer support for collaborative designing. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures '95, pp. 727-37. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore
- Saad, M. & Maher, M. L. (1996) Shared understanding in computer-supported collaborative design. *Computer-Aided Design*, 28(3), 183-92
- Salvadori, M. G. (1974) Is automated architectural design possible. In *Basic Questions of Design Theory*, ed. W. R. Spillers, pp. 95-102. New York: American Elsevier Publishing Co. Inc.
- Sanders, K. (1996) *The Digital Architect*. New York: Wiley
- Sanders, K. (1997) Firmwide networks. *Architecture*, March, 122-5
- Savage, C. (1996) Job site information systems. *A/E/C Systems Computer Solutions*, September-October, 29-32
- Schegloff, E. A. (1991) Conversation analysis and socially shared cognition. In *Perspectives on Socially Shared Cognition*, ed. L. B. Resnick, J. M. Levine & S. D. Teasley, pp. 150-71. Washington DC: American Psychological Association
- Schmidt, K. & Rodden, T. (1996) Putting it all together: Requirements for a CSCW platform. In *The Design of Computer Supported Cooperative Work and Groupware Systems*, ed. D. Shapiro, M. Tauber & R. Traunmüller, pp. 157-75. Amsterdam: Elsevier
- Schön, D. A. (1983) *The Reflective Practitioner: How Professionals Think in Action*. New York: Basic Books Inc.
- Schön, D. A. (1985) *The Design Studio: An Exploration of Its Traditions and Potentials*. London: RIBA Publications Ltd.
- Schön, D. A. (1987) *Educating the Reflective Practitioner*. San Francisco: Jossey Bass



- Schön, D. A. & Wiggins, G. (1992) Kinds of seeing and their functions in designing. *Design Studies*, 15(2), 158-74
- Scrivener, S. A. R., Harris, D., Clark, S. M., Rockoff, T. & Smyth, M. (1993) Designing at a distance via real-time designer-to-designer interaction. *Design Studies*, 14(3), July, 261-82
- Scrivener, S. A. R., Urquijo, S. P. & Palmén, H. K. (1996) The use of breakdown analysis in synchronous CSCW system design. In *CSCW Requirements and Evaluation*, ed. P. J. Thomas, pp. 157-72. London: Springer-Verlag
- Shea, G. P. & Guzzo, R. A. (1987) Group effectiveness: What really matters. *Sloan Management Review*, 28(3), Spring, 25-31
- Shelden, D., Bharwani, S., Mitchell, W. J. & Williams, J. (1995) Requirements for Virtual Design Review. *Architectural Research Quarterly*, 1(2), December
- Sherry, L. & Myers, K. M. (1998) The dynamics of collaborative design. *IEEE Transactions on Professional Communication*, 41(2), June, 123-39
- Shibley, R. G. (1989) Architectural excellence: Framing the debate. In *In Search of Design Excellence*, ed. T. Vonier, pp. 57-76. Washington: American Institute of Architects Press
- Short, J. (1974) Teaching by telephone: The problems of teaching without the visual channel. *Teaching at a Distance*, 1 (November), 61-6. Milton Keynes: Open University
- Siegel, J., Dubrovsky, V., Kiesler, S. & McGuire, T. (1986) Group processes in computer-mediated communication. *Organizational Behavior and Human Decision Processes*, 37, 157-87
- Simon, H. A. (1969) *Sciences of the Artificial*. Cambridge MA: MIT Press
- Simon, H. A. (1979) *Models of Thought*. New Haven: Yale University Press
- Simon, H. A. (1996) *Sciences of the Artificial*, third edition. Cambridge MA: MIT Press
- Sonnenwald, D. H. (1996) Communication roles that support collaboration during the design process. *Design Studies*, 17, 277-301
- Soufi, B. & Edmonds, E. A. (1996) The cognitive basis of emergence: Implications for design support. *Design Studies*, 17, 451-63

- Søby, M. (1992) Waiting for Electropolis. In *Collaborative Learning Through Computer Conferencing: The Najaden Papers*, ed. A. Kaye, pp. 39-49. New York: Springer-Verlag
- Sproull, L. S. & Kiesler, S. (1991) *Connections : New Ways of Working in the Networked Organization*. Cambridge, Mass.: MIT Press
- Steiner, I. D. (1972) *Group Process and Productivity*. New York: Academic Press
- Stitt, F. A. (1984) *Systems Graphics*. New York: McGraw Hill
- Suchman, L. A. (1987) *Plans and Situated Actions*. Cambridge: Cambridge University Press
- Suchman, L. A. (1993) Response to Vera and Simon's Situated action: A symbolic interpretation. *Cognitive Science*, 17(1), 71-5
- Sudweeks, F. & Allbritton, M. (1996) Working together apart: Communication and collaboration in a networked group. In *Proceedings of the 7th Australasian Conference of Information Systems, Vol. 2*, ed. C. D. Keen, C. Urquhart & J. Lamp. ACIS96, pp. 701-12. Department of Computer Science, University of Tasmania
- Sudweeks, F. & Rafaeli, S. (1996) How do you get a hundred strangers to agree: Computer mediated communication and collaboration. In *Computer Networking and Scholarship in the 21st Century University*, ed. T. M. Harrison & T. D. Stephen, pp. 115-36. SUNY Press
- Suwa, M. & Tversky, B. (1997) What do architects and students perceive in their design sketches? A protocol analysis. *Design Studies*, 18, 385-403
- Tang, J. C. (1991) Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies*, 34, 143-60
- Tang, J. C. & Minneman, S. L. (1990) Videodraw: A video interface for collaborative drawing. In *ACM SIGCHI Conference on Human Factors in Computing Systems*, pp. 313-20. ACM Press
- Tang, J. C. & Isaacs, E. (1993) Why do users like video. *Computer Supported Cooperative Work*, 1, 163-96
- Thompson, A. (1990) *Architectural Design Procedures*. London: Edward Arnold
- Tombesi, P. (1997) Travels from Flatland: The Walt Disney Concert Hall and the specialization of design knowledge in the building sector. Ph. D. Diss. Los Angeles: University of California

- Turkle, S. (1995) *Life on the Screen*. London: Weidenfeld & Nicolson
- Vaitkus, S. (1991) *How is Society Possible*. Dordrecht: Kluwer Academic Publishers
- Vera, A. H. & Simon, H. A. (1993) Situated action: Reply to reviewers. *Cognitive Science*, 17, 77-86
- Vera, A., Kvan, T., West, R. & Lai, S. (1998) Expertise and collaborative design. In *CHI'98 Conference Proceedings*. CHI'98, pp. 503-10. Los Angeles: ACM
- Verstijnen, I. M., Hennessey, J. M., van Leeuwen, C., Hamel, R., & Goldschmidt, G. (1998) Sketching and creative discovery. *Design Studies*, 19, 519-46
- Vervenne, D., Rogge, S., Van Laere, W. & Vandamme, F. (1995) AnnotAgents: Knowledge-based tools for supporting participatory design. In *The Global Design Studio*, ed. M. Tan & R. Teh. CAAD Futures, pp. 699-706. Singapore: Centre for Advanced Studies in Architecture, National University of Singapore, 24-26 September
- Virtual A/E firm. (1994) *Principal's Report*, November, 11
- Vonier, T. (1989) *In Search of Design Excellence*. Washington: American Institute of Architects Press
- Watson, R. T., DeSanctis, G. & Poole, M. S. (1988) Using a GDSS to facilitate group consensus: Some intended and unintended consequences. *MIS Quarterly*, 12, 463-77
- Wenz, F. & Hirschberg, U. (1997) Phase(x) - Memetic engineering for architecture. In *15th ECAADE Conference Challenges of the Future, CD-Rom Imprint*, ed. B. Martens, H. Linzer & A. Voigt. ECAADe '97. Österreichischer Kunst- und Kulturverlag, 17-20 September
- Whittaker, S. & O'Conaill, B. (1997) The role of vision in face-to-face and mediated communication. In *Video-Mediated Communication*, ed. K. E. Finn, A. J. Sellen & S. B. Wilbur, pp. 23-49. Mahwah, NJ: Lawrence Erlbaum Associates
- Wiener, N. (1954) *The Human Use of Human Beings: Cybernetics and Society*, pp. 97-8. Boston: Houghton Mifflin
- Wojtowicz, J., Cheng, N. & Kvan, T. (1995) Postscript: The virtual design studio 1994. In *Virtual Design Studio*, ed. J. Wojtowicz, pp. 131-51. Hong Kong: Hong Kong University Press



- Wojtowicz, J., Davidson, J. & Mitchell, W. J. (1992) Design as digital correspondence. In *Computer Supported Design in Architecture*, ed. K. Kensek & D. Noble. ACADIA '92, pp. 89-101. ACADIA
- Wojtowicz, J., Papazian, P., Fargas, J., Davidson, J. & Cheng, N. (1993) Asynchronous architecture. In *The Critical Interface*, ed. F. Morgan & R. W. Pohlman. ACADIA '93, pp. 107-17. ACADIA
- Woo, S., Kim, I., Lee, E. & Sasada, T. (1997) The multi-user workspace as the medium for communication in collaborative design. In *Proceedings of the Second Conference on Computer Aided Architectural Design Research in Asia*, ed. Y.-t. Liu, J.-Y. Tsou & J.-H. Hou. CAADRIA '97, pp. 133-42. National Chiao Tung University, Hsinchu, Taiwan: Hu's Publisher Inc., 17-19 April
- Wright, I. (1997) A review of research into engineering change management: Implications for product design. *Design Studies*, 18, 33-42
- ZGFNet. (1997) *Architecture*, March, 126
- Zhang, J. (1997) The nature of external representations in problem solving. *Cognitive Science*, 21(2), April-June, 179-217
- Zhang, J. & Norman, D. A. (1994) Representations in distributed cognitive tasks. *Cognitive Science*, 18, 87-122
- Zuboff, S. (1988) *In the Age of the Smart Machine: The Future of Work and Power*. New York: Basic Books Inc.